

SOCIAL HOUSING BUILDING ENVELOPE RETROFIT IN RUSSIA

NEW MATERIAL ASSEMBLY APPLICATION

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Abstract

In the 1950's the Russian government began a massive construction campaign to provide housing throughout the country. Millions of units were built with minimal variation to supply housing demand. The driving force was to keep the cost of construction as low as possible; as a result these buildings were built with no energy efficiency standards. In addition, the interior of these buildings have very poor thermal comfort. These units had an intended lifespan of 25 years but, unfortunately, are still in use today. This fact together with an outdated and failing district heating infrastructure has resulted in a substantial need for improved building envelope retrofits of these old prefabricated concrete buildings.

Various retrofit options have been studied in Moscow since 1997, when the building codes in Russia changed to incorporate energy efficiency in the building envelope design. The most recent study by VTT (VALTION TEKILLINEN TUTKIMUSKESKUS) Technical of Finland in 2014, was very thorough in overall scope, but had several areas where it could be improved.

The answer is fiber cement and cellulose insulation in a prefabricated building element. As no such building element currently exists, the culmination of this research document results in the creation of a new building material assembly that is ideally suited for sustainable prefabricated building envelope retrofits. There is a need for this new material assembly because it will provide a better, more adaptable, less expensive, easier to install, more sustainable, lower lifetime maintenance exterior insulation system than any other material on the market today. The site location selected for study is in Volzhsky, a small but progressive city in the south western corner of Russia. The social housing retrofit proposed herein will provide a precedent that can be followed and modified throughout the entire country.

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Introduction

There is an opportunity to improve building envelope energy efficiency in the outdated social housing projects located in the Russian city of Volzhsky, by retrofitting the building envelopes through the use of a better, more adaptable, less expensive, easier to install, more sustainable, lower lifetime maintenance exterior insulation system. The vision of this opportunity resulted from a thorough investigation of Russia's housing and heating systems, which currently are in need of extensive improvement and updating throughout the country. However, the poor condition of Russia's current housing and heating infrastructure did not happen overnight and the Russian Government is well aware of the need to retrofit these buildings.

The purpose of this doctorate project is to investigate and determine the potential areas of improvement in the energy efficiency of the old social housing buildings in Russia. This analysis examines:

- Public housing in Russia/Former USSR
- Current methods of heating and cooling residential spaces
- Current living conditions
- Russia's plans to address energy inefficiencies
- Green energy systems currently in use in Russia
- Possible low expense alternative heating systems
- Inefficiencies of the current insulation and heating systems
- Leading building retrofit options in the country

-
- The best alternative for exterior insulation retrofit that can be applied to social housing buildings in Russia

After the Russian Revolution in 1917, the government of the Union of the Soviet Social Republics (USSR) had political objectives to eradicate the massive housing shortage that had occurred throughout the country. An inexpensive housing system was developed and adapted over the next 30 years. In 1947, a 5-story prefabricated concrete building typology was created and implemented throughout the entire country as the answer to Russia's housing problem. Between 1947 and 1964, this 5-story typology was the primary housing, built to supply apartments to the entire country. From 1964 until the fall of the Soviet Union in 1991, a taller 9-story variation was used to increase the density in the cities and reduce sprawl. These housing units were designed as a temporary housing solution with only a 25 year lifespan. They were constructed quickly and inexpensively because the Russian government intended to replace them with better, longer lasting apartments in the future.

Today these old social housing apartments are still in use and have not only been used well past their intended lifespan, but due to lack of maintenance over the years, have fallen into serious disrepair and in many areas, are considered to be a substandard form of housing. In addition, when these buildings were designed and constructed, the country had no energy efficiency or building insulation requirements in their building code and as a result, these buildings have very poor insulation resulting in substantial heat loss through the building envelope in winter.

The Russian residential sector has two major areas where energy efficiency can be improved. The first lies in potential improvements to the country's district heating systems throughout the country which today, due to lack of maintenance and advanced age, have an average running efficiency of only 58.4 percent, as compared to the district heating leader of Copenhagen at between 85-95% depending on the fuel type . As

Russia has the largest district heating system in the world, with over 180,000 miles of piping throughout the country, improving the heating system would lead to substantial energy savings and has the potential to save the country billions of dollars annually in fuel cost. However, due to the immense size of the country, updating the entire district heating system would require such an immense financial investment that Russia is looking to private funding sources. Because of this, Russia currently has no long term system improvement plans and thus far, Moscow is the only Russian city to receive a full system upgrade to its district heating.

The second area for energy efficiency improvement focuses on individual buildings. Russia has examined two options: replacement of the old outdated social housing buildings with new more energy efficient apartment buildings; or more specifically retrofitting the exterior walls of existing buildings to make them more energy efficient. Either of these approaches would not only improve the psychological conditions of the residents, but also would drastically decrease the energy demand of the buildings which in turn, could save the country massive amounts of money currently being spent on heating these poorly insulated buildings.

After improving the district heating system in Moscow, Russia determined that this option was far too expensive to implement throughout the rest of the country. Consequently, Russia is now trying to find new alternative options for retrofitting existing housing that would be less expensive. The most recent study of Russian retrofits was released in 2014 by VTT Technical Research Center of Finland. This study examined and retrofitted 327,581 square meters of old Russian social housing apartment buildings. They examined 3 different levels of retrofit improvements, each being more extensive than the previous and they also examined the possibility of replacing the heating systems with solar and a thermal heat pump. The VTT Technical retrofit study was very thorough as it also investigated potential financing options and incentives.

While the VTT Technical retrofit study is both impressive and incredibly thorough, it did not, unfortunately, generate the best possible option for an exterior retrofit of a building in terms of utilizing the most cost effective and affordable or even the most sustainable exterior insulation system. The VTT Technical retrofit options specified the use of mineral wool insulation with a plaster coat finish. There are far more sustainable and less expensive insulation materials that could have been used for the VTT Technical retrofits. The preferred material system combination would use fiber cement and cellulose insulation and while the individual material components are used extensively in residential construction. The combination of these materials into a unified singular exterior insulation system has yet to be created. This new exterior insulation system is the subject of this doctorate project.

Building envelope retrofits are often an area of increasing need throughout the world, largely due to the fact that it is more cost effective to refurbish and reuse an existing building than it is to purchase it, demolish it, and rebuild it with a new building of equal size. In this doctorate project, materials have been combined to create a new prefabricated insulated building panel to retrofit the exteriors of these existing buildings for significant savings and increased sustainability. This new material insulation system has the potential to help revolutionize the prefabricated insulated panel market and building envelope design by offering a less expensive sustainable material that still has the adaptability and aesthetic appeal of the previous prefabricated insulated panels that came before it.

This new material insulation system will be applied to an existing 9-story prefabricated apartment building in the city of Volzhsky, Russia. Volzhsky, like many smaller Russian cities, is not receiving the same level of attention and upgrades as Moscow. Consequently, it is in need of a retrofit option that will be applicable to smaller less wealthy cities throughout the country. The buildings here are identical to the

buildings in Moscow due to the mass produced quality of the design. However, unlike Moscow, the district heating system is not in need of massive replacement due to the fact that the entire heating and power sector for the entire southern region of Russia is privately owned by one of Russia's largest private oil company Lukoil. They have the financial means to maintain the system. Consequently, the major need in Volzhsky is for the individual building improvements. With proper upgrades this city could provide an example for the rest of the country.

Extended Literature Review

Chapter 1: Social Housing Development in Russia

History and Development of Social Housing in Russia

Communal or social housing in Russia today is an aged run down system of buildings that were constructed during the massive housing push that began in 1938 and ran strong until the early 1970s.¹ The governing had a desire to make things better for the common citizen of Russia and this included an improvement of the housing situation. As with many nations around the world the industrial revolution that began in the 1890s, had led to a much larger urban population and as such a large city housing shortage in the USSR had to be improved.

“An important task of the government since the early days of Soviet Russia was to provide housing for the population.”² Housing construction standards that were developed during the first stages of this new government took on the principals of “minimum cost -maximum comfort.”³ This refers more to a systematic or almost mathematic and economic approach to the design process. “The first major housing project after the revolution, the Sokol Co-operative settlement in the north of the city (Moscow) was a Russian Equivalent to Mock Tudor-deliberately dreamy and retrograde. Like much wooden housing, it is also basically prefabricated, ‘dry’ construction slotted together rather than made via messy ‘wet trades’ of bricks, cement or concrete.”⁴

Beginning in 1932, many approaches in Soviet architecture changed as new, more specific, goals were created. This was done to prepare for mass construction across the country. Certain specifications in design and construction began to have a regulatory

1 Owen Hatherley, “Block Party: Owen Hatherley Celebrates a Much-Maligned Housing Project,” (The Calvert Journal, January 27 2014)

2 Vasil’evich, Shagov Nikolay, “Development of Standard Housing in Soviet Russia from 1917 till [sic] 1940, РАЗВИТИЕ ТИПОВОГО ЖИЛИЩНОГО СТРОИТЕЛЬСТВА В СОВЕТСКОЙ РОССИИ С 1917 ПО 1940 г.” *Vestnik MGSU*, 2013(4)

3 Vasil’evich, Shagov Nikolay, “Development of Standard Housing in Soviet Russia”

4 Owen Hatherley, “Block Party: Owen Hatherley Celebrates a Much-Maligned Housing Project,” (The Calvert Journal, January 27 2014)

framework. One major thought process evolution was in the concept of desired per capita living space minimums which changed from meters squared to cubic volume of air. For example, an adult needed to have 30 cubic meters of air and a child under the age of 14 not less than 20 cubic meters of air. The Soviet government believed that these numbers represented the ideal amount of air needed in a room to have maximum oxygen recovery at night during sleep which would lead to more productive workers.⁵

Despite all of these changes and the initial sacrifice of quality for quantity, there was still a prevailing sense that there building projects were not meeting the objectives of the Soviet government. The “Union of Soviet Architects of the USSR (1936) stated: ‘We are still building homes too slow, too expensive, not enough for comfortable accommodation and is not always beautiful. Construction of residential buildings without research of model projects, without extensive use of standards, industrial production methods is the bane of mass housing.’”⁶ In essence, the Soviets wanted mass housing to be cheaper and faster and they didn’t care how this was accomplished.

Mass Production of Housing

The years of 1938-1970 marked a new era in the housing agenda in the USSR. From 1938 until the mid-1940’s housing typologies were developed to determine the best single design to use for the country as a whole. Because the country as well as the rest of Europe was at War, it was a time to create policies and develop and action plan. The Soviet Union had decided that they needed to produce houses cheaper and faster to meet the housing demand. Housing projects commenced and newer and cheaper standards were set. Some of the major design decisions were created by Architect Chales-Edouard Jeanneret-Gris, better known as Le Corbusier, who was influential architect in the modern movement. Le Corbusier helped to create some of the standardized principals in the communal housing blocks during this era. However, as is always the case with everything when “cheap and fast” are the driving factors

⁵ Vasil’evich, Shagov Nikolay, “Development of Standard Housing in Soviet Russia”

⁶ Vasil’evich, Shagov Nikolay, “Development of Standard Housing in Soviet Russia”

behind design decisions the product quality at the end was lacking in many ways.

One major area where the construction costs were minimized was in the building insulation levels, where little to no insulation was built into the exterior walls of these buildings. The housing projects constructed during this era have come to be referred to as “The Khrushchev Slums”⁷ as dubbed by many of the inhabitants today. In historical reference, it is better referred to as the “Khrushchev era” after Nikita Khrushchev who was the dominant political power in the Soviet Union during the height of the Cold War, serving as premier from 1958 to 1964.⁸ The building projects began in 1938 block on Leningandsky Prospekt by Andrei Burov who was a student of Le Corbusier.

“Housing construction received a major boost in the fifth five-year plan (1951-55) when investment reached almost twice the amount of the preceding planning period. It more than doubled again in the next five-year plan period (1956-60) when it amounted to an all-time high of 23.5 percent of total capital investment. Quality of construction and amenities were sacrificed for the sake of easing the shortage of housing. Many of the apartments constructed in the 1950s were prefabricated four- and five-story buildings, popularly known as khrushcheby, a play on the word trushcheby, which means slum.”⁹ Ultimately the new Party Program of 1961, “which promised that during the first decade of the building of communism (1961-70) the housing shortage will be eliminated ...,” was far from having been realized.¹⁰ In a sense, this could be said to be a failure because the Russian government continually sacrificed quality for quantity in the goal of satisfying housing needs which were never truly met. Today what remains of these housing projects are decaying buildings that never satisfied basic housing needs and have since deteriorated into slums.

There were several series of construction projects that occurred in the Soviet

7 Lewis Siegelbaum, “1961: The Khrushchev Slums: Housing Construction under Khrushchev,” (Seventeen Moments in Soviet History)

8 “Nikita Khrushchev.” History.com. September 6, 2014. A+E Networks. 2009.

9 Siegelbaum, “The Khrushchev Slums”

10 Siegelbaum, “The Khrushchev Slums”

Union. “The Soviet Block Housing System or Khrushchyovka, was designed by engineer Vitaly Lagutenko to be rapidly deployed as a low cost solution to a severe housing shortage from 1947 to 1961. Based on a paneled design, Khrushchyovkas utilized concrete plants in which most of the construction occurred in the factory and trucked to be assembled at site. As traditional masonry was labor-intensive and individual projects were not scalable to the needs of overcrowded cities, the Khrushchyovka was an early attempt at mass-produced industrial construction with 64,000”¹¹ units in Moscow alone. A basic floor plan of these units is in Figure 1.1. They were grouped in sets of four apartments for maximum efficacies of space and material. This plan could then be repeated linearly over and over again until the desired density of the housing area was achieved.

Housing units within the Lagutenko design were not all the same size. They varied from one room units up to 3 bedroom units. The image Figure 1.1 to the right had a layout of four apartments consisting of two units with two bedrooms in each and two units with one bedroom in each. In the second floor plan Figure 1.2, the layout was altered to create three units with one bedroom in each and one unit with two bedrooms. The plan in Figure 1.2 differed in its interior layout from the floor plan in Figure 1.1; however both still maintain the same total number of units and the same total floor area. These variations allowed for a greater variety in unit configurations while still maintaining as much similarity as possible in the exterior of final construction. The major differences in the layouts of the units were based primarily on the interior wall configurations which could be changed depending on the desired unit configurations.

The designs created by Lagutenko may have satisfied the Soviet demands for cheaper and faster housing but they did not satisfy basic livability standards. “The

very symbol of sub-standard living, the lowly khrushchyovka” has been ridiculed for its

11 Flexus Foundation, “Fluxhouse™ and Khrushchyovka,” 2014 George Maciunas Foundation Inc./DBA Fluxus Foundation

Figure 1.1: Khrushchyovka Housing Plan

K. Metel'skii, "Predlozheniia proektirovshchikov MITEPa," Arkhitektura SSSR, no. 6 (1962): 13.

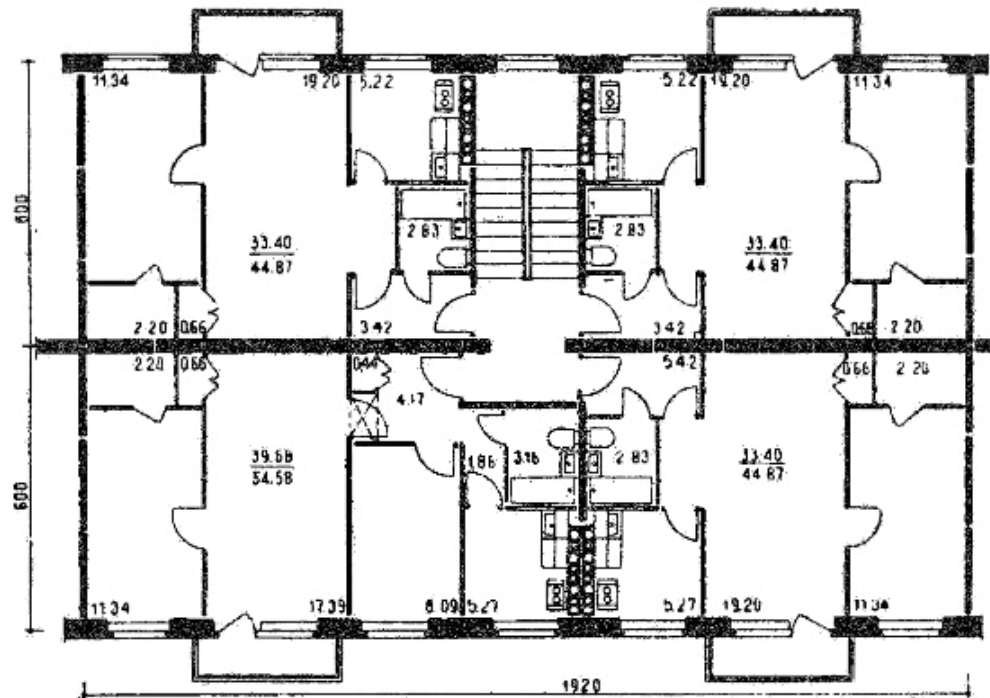
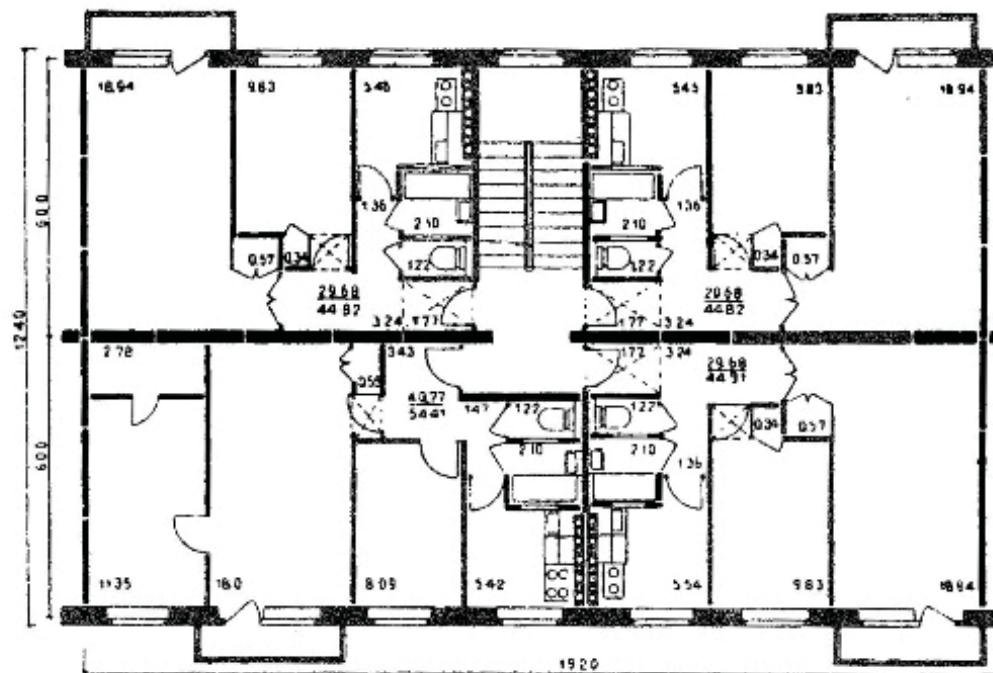


Figure 1.2: Khrushchyovka Housing Plan

K. Metel'skii, "Predlozheniia proektirovshchikov MITEPa," Arkhitektura SSSR, no. 6 (1962): 13.



cramped living space consisting of 300 square feet per unit.¹² When only looking at cost and speed as design criteria, many unappealing design approaches were considered. One example of this was that the “theorists considered combining the toilet bowl functions with the shower’s sink –luckily, this idea was later discarded.”¹³ However, the greatest downside of this approach was the unrealistic assumption that they could compromise quality of construction since the units were intended to have a 25 year lifespan and then be replaced. Instead buildings designed for a 25 year lifespan are still in use almost 70 years later. The sad reality is these buildings need a major overhaul but the expense to do so would be astronomical because of the massive number of buildings being improved. In Figures 1.3 and 1.4 are a few images of the Krushchyovka style design. The design may have been efficient, but it is lacking in any form of aesthetic appeal.

Up until 1961 the Lagutenko designs were configured in 5-story buildings. The later designs that followed, maintained similar principals, but the buildings were made taller due to the desire to accommodate a greater population density in the cities. In the 1960s, the Lagutenko design apartments were incorporated into 9-story tall building typologies, eventually increasing to 12-story and sometimes 16-story buildings in the 1970s. However, the guiding principles remained the same and these 12 and 16 story building typologies only represent a small fraction of the social housing sector in Russia. The 9-story typology was by far the most repeated system of construction after the 5-story began to be phased out. Figure 1.5 is a perspective hand drawn sketch of a typical 9-story social housing building. Because of the repetitive nature of the designs these buildings would be constructed back to back and could extend the entire length of the block. It was not uncommon for as many as 8-10 buildings or more to be connected together with typically 4 units per floor per building.

For the most part the Soviet government considered the Krushchyovka design

¹² Flexus Foundation, “Fluxhouse™ and Khrushchyovka,”

¹³ Flexus Foundation, “Fluxhouse™ and Khrushchyovka,”

Figure 1.3: Khrushchyovka 1960's

K. Metel'skii, "Predlozheniia proektriovshchikov MITEPa," Arkhitektura SSSR, no. 6 (1962): 13.<http://fluxusfoundation.com/exhibitions/fluxhousefluxcity-prefabricatedmodular-building-system/fluxhouse-and-khrushchyovka/>



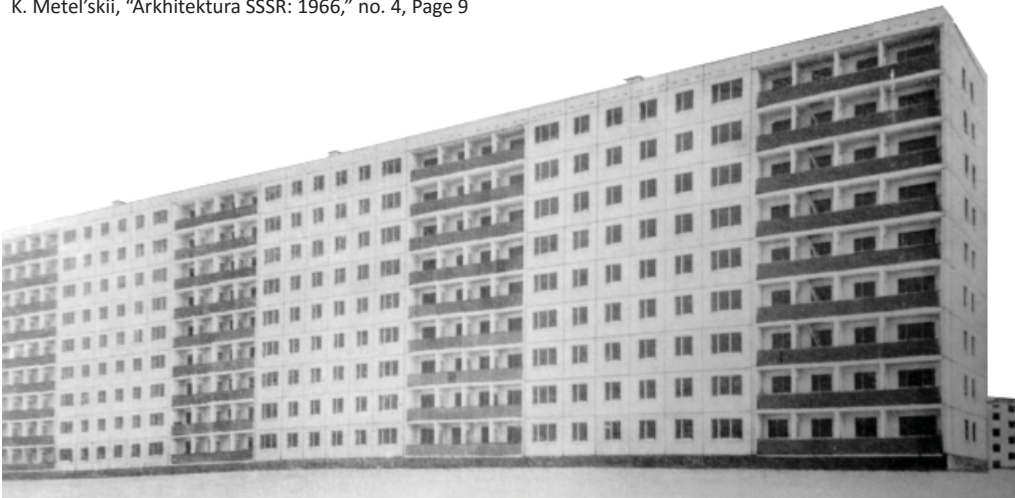
Figure 1.4: Khrushchyovka Today

K. Metel'skii, "Predlozheniia proektriovshchikov MITEPa," Arkhitektura SSSR, no. 6 (1962): 13.<http://fluxusfoundation.com/exhibitions/fluxhousefluxcity-prefabricatedmodular-building-system/fluxhouse-and-khrushchyovka/>



Figure 1.5: 9-Story Social Housing Perspective Drawing

K. Metel'skii, "Arkhitektura SSSR: 1966," no. 4, Page 9



to be very successful so minimal changes were made in the next iterations of social housing buildings. Most changes were small variations in panel size and in different roof conditions. The first 5-story buildings had a pitched roof condition, however, later iterations had a flat roof condition that housed some form of mechanical systems and provided a little insulation for the units directly below.¹⁴

The massive social housing boom continued until the 1980's, largely using the 9-story typology established in Moscow for a higher population density in the cities. In, 1979, energy reforms began to be incorporated in the USSR. These reforms led to a higher construction standard for buildings constructed from 1980 forward. In Moscow, there has been a major housing improvement initiative that has been addressing some of the issues and drawbacks of the earlier designs. However, in many cases instead of retrofitting the buildings, they have been torn down and rebuilt with a new form of panel style prefabricated building. These new buildings have the advantage of newer technology and higher energy efficiency standards.¹⁵

Due to the mass produced quality of these buildings in Russia, any housing retrofits to both the heating and the exterior façade for improved insulation can be mass produced as well, making the overall cost of the improvements to the national housing supply more affordable. These buildings have been in use far beyond their intended life expectancy and therefore should be given the improvements necessary to make them a viable place to live until Russia can afford to have new housing units rebuilt across the rest of the country.

14 K. Metel'skii, "Arkhitectura SSSR: 1960," no. 1-12

15 Krashenninokov, Alexander, "Urban Slums Report: The Case of Moscow, Russia."

Figure 1.6: Prefab Unit Installation

<https://vespig.wordpress.com/2014/03/30/%D0%BA%D0%B0%D0%BA-%D1%81%D1%82%D1%80%D0%BE%D0%B8%D0%BB%D0%B8-%D1%85%D1%80%D1%83%D1%89%D1%91%D0%B2%D0%BA%D0%B8/>



Figure 1.7: Prefab Unit Installation

<https://vespig.wordpress.com/2014/03/30/%D0%BA%D0%B0%D0%BA-%D1%81%D1%82%D1%80%D0%BE%D0%B8%D0%BB%D0%B8-%D1%85%D1%80%D1%83%D1%89%D1%91%D0%B2%D0%BA%D0%B8/>



Chapter 2: District Heating in Russia

District Heating is a “network of insulated pipes used to deliver heat, in the form of hot water or steam, from the point of generation to an end user”.¹ When operated efficiently many district heating networks can be used as a form of combined heat and power by taking the resulting heat from energy generation and circulating it through a district heating network. Most district heating networks have their own heat generation power source in order to handle the demand, rather than having power supplied by another utility source.² Modern day district heating networks such as those in Western Europe offer several efficacies over many other forms of traditional heating methods. These modern systems use very well insulated pipes and heat generation plants that make district heating a viable source of heating on a large number of buildings or city. They are typically relatively efficient with approximately 85%-95% of fuel utilized being converted into heat and or energy as further explained below. However, older systems are far less energy efficient and as such, would require an extensive overhaul of their massive piping networks in order to improve their inefficiencies. The vast majority of the district heating systems in Russia have aged infrastructure that has about 58.4% fuel efficiencies as detailed below.

District Heating is a very common form of mass heating production and there are many countries that have district heating including the United States. District heating is very popular in Many European countries including France, Italy, Denmark, Austria, Germany, and of course, in all of the countries that were once part of the former USSR including Russia.³ Many of the countries in Europe, as well as the United States, incorporate many forms of heat generation including recycled heat from sources like

1 Association for Decentralized Energy, “What is District Heating?”

2 Association for Decentralized Energy

3 Euroheat and Power. Brussels, Belgium, District Heating and Cooling Statistics, “Statistics Overview 2011”

combined heat and power. However, many of the countries that were part of the former Soviet Union do not have heat generation from combined heat and power.

District Heating in Russia

Russia has the largest district heating network in the world with approximately 180,000 miles of pipes throughout the country.⁴ They use primarily fossil fuels (over 66% of the fuel used for district heating come from natural gas)⁵ to power their district heating system that is then generated at boilers and piped as hot water throughout the entire system. As of 2007 Russia had 17,183 different heat production plants to provide heat through their 180,000 miles of piping⁶. That is an average of around 10 miles of piping per heat production facility.

Russia's capital city of Moscow has the largest network of district heating of any city in the world with 5,932 miles of piping. This is 10 times larger than the district heating network in Paris, France. In addition, the Moscow district heating network is continuing to grow, adding approximately 150-200 kilometers of piping per year,⁷ which is the equivalent of (93-124 miles per year). However, Moscow's district heating network, like all the district heating networks in Russia, has aged infrastructure having originally been built in 1902, it is well over 100 years old and is currently receiving a major overhaul.⁸ The majority of the existing pipes in Russia's district heating system are cast iron pipes that are above ground for easier servicing.⁹

Modernization of Moscow's District Heating System

As of 2008, a plan was initiated to replace 70% of the Moscow district heating

4 Shmelev, Alexander and Dmitry Ostrovsky, "District Heating in Moscow - a Warm Smile from Cold Russia," International District Heating, Case Studies

5 Evans, M and Roshchanka, V. "Playing Hot and Cold: How can Russian Heat Policy Find its Way Toward Energy efficiency?" US Department of Energy, Pacific Northwest National Laboratory, October 2012, page 1

6 International Energy Agency, IEA. 2011, "World Energy Outlook 2011," OECD Publishing, Paris

7 Alexander Shmelev, and Dmitry Ostrovsky, "District Heating in Moscow"

8 Alexander Shmelev, and Dmitry Ostrovsky, "District Heating in Moscow "

9 Alexander Shmelev, and Dmitry Ostrovsky, "District Heating in Moscow "

pipelines.¹⁰ The Russian government is funding this project in Moscow. Russia is not, replacing the Moscow pipes with the original designed cast iron piping, but is instead installing “flexible preinsulated polymer pipes.”¹¹ The first pipe replacements came from outside Russia. However due to the massive district heating network and resulting expense, Russia built its own manufacturing plant and now manufactures a similar version of the new piping. Russia designed piping that is more suited to its specific needs, fabricating pipe that is 6 inches in diameter, and not the standard 4 inch diameter in order to handle its massive demand. In addition, Russia’s new piping can handle almost twice the water pressure (145 PSI) as compared to the European standard (87 PSI).¹² The new Russian pipe is Kevlar which is both stronger and thinner, allowing for greater flexibility. Russia also designed custom pipe fittings and connections so that the entire network would have the same stress load capabilities.

Modernization of District Heating Throughout the Rest of Russia

The need for modernization of Russia’s entire district heating system is incredibly important as “about 73 percent of the Russian population—92 percent in urban areas and 20 percent in rural areas—depend on Russia’s district heating sector, the largest in the world.”¹³ “The scale of needed investments is significant and reflects decades of underinvestment: about 70 percent of the district heating infrastructure needs replacement or maintenance, as is estimated by the Russian government.”¹⁴

The majority of the district heating piping is not the only area in need of a replacement; a large percentage of the heat generation portion of the network needs to be replaced as well. International Energy Agency’s (IEA) World Energy Outlook 2011 reported that “80 percent of Russian boilers are over 30 years old (20 percent are over

10 Alexander Shmelev, and Dmitry Ostrovsky, “District Heating in Moscow”

11 Alexander Shmelev, and Dmitry Ostrovsky, “District Heating in Moscow”

12 Alexander Shmelev, and Dmitry Ostrovsky, “District Heating in Moscow”

13 Evans, M and Roshchanka, V. “Playing Hot and Cold” Page 1

14 Evans, M and Roshchanka, V. “Playing Hot and Cold” Page iii

50 years old), and over half of the 200,000-kilometer network of pipelines are past their technical life expectancy.”¹⁵

Russians pay for district heating through a tariff system. Currently, throughout most of the country tariff revenue “does not cover the full costs of district heating. This has made it hard to modernize or even maintain district heating systems, which has led to growing inefficiency and service disruptions.”¹⁶ The specific site location for this doctorate thesis is Volzhsky, and has a privately owned power and heating company which will be discussed later in the paper. However, the tariff issue is just part of the problem. Even though the current system does not sustain itself, many of the existing tariffs are not collected due to “poor enforcement of payment discipline.”¹⁷ In order for Russia to fund the modernization of the district heating system, these areas must be improved upon. In the meantime, the system will continue to degrade and demand will continue to grow, making the system more and more inefficient and incapable of supplying the full needs of the Russia’s population.

District Heating Efficacies

The district heating system in Russia has poor energy efficiencies, largely due to the “aging infrastructure, but also to limitations of the heat policy and market structure.”¹⁸ The heat losses of the district heating network can be broken into two categories; losses based on heat production and losses based on heat distribution. The district heating network has several forms of heat generation and each one, based on its age and form of fuel, has its own efficiency levels. “The average heat boiler efficiency is reported at 73 percent..., with some studies citing an average efficiency of 33 percent for older coal plants and 36 percent for older gas-fired plants.... For comparison, production efficiency in district heating systems in Western Europe is estimated to be 85 to 95

15 Evans, M and Roshchanka, V. “Playing Hot and Cold” Page 3

16 Evans, M and Roshchanka, V. “Playing Hot and Cold” Page iii

17 Evans, M and Roshchanka, V. “Playing Hot and Cold” Page iii

18 Evans, M and Roshchanka, V. “Playing Hot and Cold” Page 3.

percent (IEA 2004).¹⁹ Many of the district heating networks in Europe provide examples of acceptable energy efficacies. Many of these systems are relatively new and use more efficient forms of heat generation than the tradition fossil fuel approach.

From the distribution side, the efficacies of Russian district heating are reported to be around 80 percent on average; however in some circumstances the efficacies are even lower. This is in comparison with Europe's district heating efficiencies of 90-95% during the distribution.²⁰ The major difference between the efficacies of Russia's system and the efficiencies of the European standard, are based on far better and newer insulated piping system that is typically buried in the ground. Again European systems stand as an example of the realistic efficiencies of district heating systems that are well operated and maintained.

Energy Costs

When adding these energy efficacies together, Russia is operating at about 12 percent less efficient at heat production and 10 percent less efficient in its piping network as compared to European district heating systems. From production to delivery the Russian systems are 21.2% less efficient than the updated European models overall the Russian systems have an efficiency of 58.4% of the total energy being used to supply the system. Russia has an estimated annual energy consumption of 114 million tons of oil equivalent to run its district heating systems.²¹ There is approximately 7.33 barrels of oil in one metric ton of crude oil.²² As of January 2015, the cost of oil per barrel in US dollars was approximately \$47 a barrel and had a one year forecasted average price of approximately \$53 a barrel.²³ This means that Russia consumes on average an estimated 832 million barrels of oil every year or around 39-44 billion US dollars a year. Russia's

19 Evans, M and Roshchanka, V. "Playing Hot and Cold" Page 3.

20 Evans, M and Roshchanka, V. "Playing Hot and Cold" Page 4.

21 Evans, M and Roshchanka, V. "Playing Hot and Cold: How can Russian Heat Policy Find its way toward Energy efficiency?" Page 1.

22 British Petroleum. "Conversion Factors: Approximate Conversion Factors of Crude Oil."

23 Oil-Price.net, "Crude Oil Commodity Prices," Updated January 23, 2015

58.4% efficiencies result in wasted energy costs of approximately 16-18 billion dollars annually. If modernized to European standards of 85% efficiencies Russia would see energy savings of approximately 8-9 billion dollars annually to operate its district heating systems.

These estimates are based on the price of oil per barrel as of January 2015. However, these oil prices are much lower than they have been in years. As recently as January 2014 the price of oil was well over \$100 a barrel.²⁴ Multiplying Russia's average annual consumption of 832 million barrels by a price of \$100 per barrel would be the equivalent of 83 billion dollars' worth of oil every year. This would be an annualized increase of 39 billion dollars over the January 2015 price of oil. Upgrading Russia's district heating to an 85% efficiency rate would reduce oil consumption to 707 million barrels of oil annually even at \$100 per barrel, the annualized value of oil consumed would be 70 billion dollars, a savings of 13 billion dollars. As oil prices in January 2015 were unusually low, the reality is that within the next few years the price of oil could easily return to \$100 a barrel or more and the energy expenses will continue to increase.

It should be noted that Russia has massive oil reserves and as such the majority of the oil being used in the country is pumped and processed in Russia. As a result, the Russians actual cost of oil is only the cost to pump, process and deliver it to their energy stations. This means that a drastically lower overall dollar amount is being spent on oil. However, looking at this from another perspective, every barrel of oil produced and consumed in Russia is a barrel that is not available to be exported to the rest of the world, in essence reducing national income which could be used, for example, to improve the current district heating network.

Current Heat Production

Russia's current heat production is generated through two main sources:

²⁴ "Crude Oil Price History Chart," Macrotrends.com, Updated 2015

approximately 55% of the heat supply is produced by heat-only boiler plants and approximately 44% being generated from cogeneration plants.²⁵ The remaining 1% is generated from other sources. Additionally, the number of heat-only boiler plants is increasing.

Figure 2.1 shows two charts; the chart on the bottom is showing the heat production by type and the chart on the top is showing different types of fuel used for the heat production. Natural gas predominates, with around 66% of all heat energy being produced using this fuel source.

District Heating and Electricity

As stated earlier, approximately 44% of the district heating is produced through a process called cogeneration also called combined heat and power. Combined heat and power “generates electricity whilst also capturing usable heat that is produced in this process. This contrasts with conventional ways of generating electricity where vast amounts of heat are simply wasted. In today’s coal and gas fired power stations, up to two thirds of the overall energy consumed is lost in this way, often seen as a cloud of steam rising from cooling towers.”²⁶ These combined heat and power plants generate approximately one-third of the country’s electricity.²⁷ The remaining two-thirds of the electricity being produced are done so by more traditional power plants.

Electricity Generation in Russia

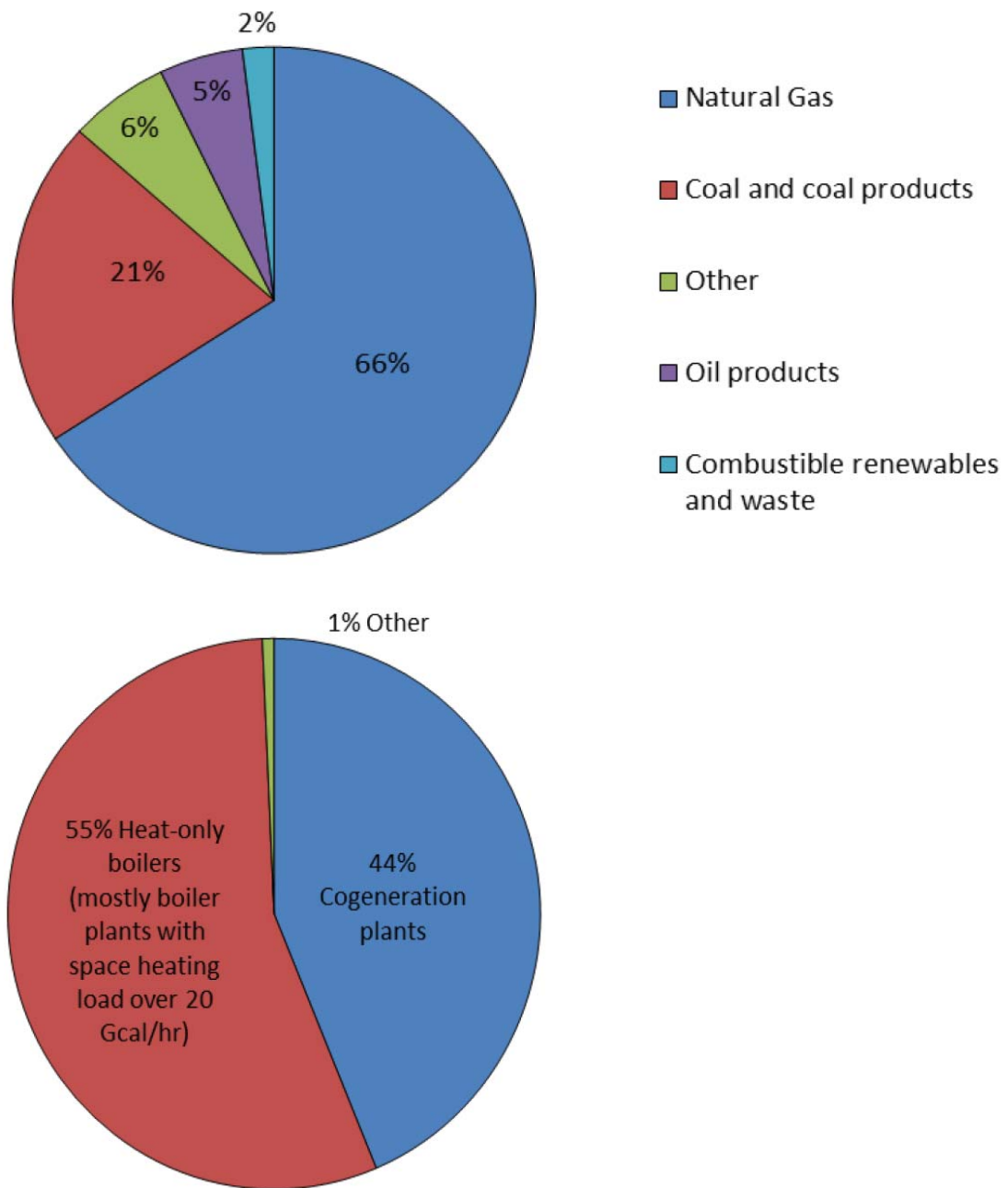
Russia has an installed capacity of more than 220 gigawatts as of 2011. Additionally, in 2011, Russia produced approximately 996 billion kilowatt hours and consumed approximately 861 billion kilowatt hours. Only about 22 billion kilowatt hours

²⁵ Evans, M and Roshchanka, V. “Playing Hot and Cold: How can Russian Heat Policy Find its way toward Energy efficiency?” Page 1.

²⁶ Association for Decentralized Energy, “What is District Heating?”

²⁷ Evans, M and Roshchanka, V. “Playing Hot and Cold” Page 16.

Figure 2.1: Heat Generation in Russia
Evans, M and Roshchanka, V page 2.



were exported to countries like Finland, China, Lithuania and a few others.²⁸ Russia uses a variety of sources to produce electric power throughout the country. “Fossil fuels (oil, natural gas, and coal) are used to generate roughly 68% of Russia’s electricity, followed by hydropower (20%) and nuclear (11%). Russia’s power sector includes over 440 fossil fuel and hydropower plants, of which 77 are coal plants. There are also 33 nuclear reactors at 10 nuclear power plants.”²⁹ Figure 2.2 is a table that shows the comparison of electricity-only production versus combined heat and power by fuel type.

Russia breaks up these energy production facilities into regions of the country or sectors. “There are eight separate regional power systems in the Russian electricity sector, seven of which are connected to the main power grid. These systems are: Northwest, Center, South, Volga, Urals, Western Siberia, Siberia, and Far East. The Far East region is the only one not connected to an integrated power system, shown in Figure 2.3. Federal Grid Company (FGC), which is more than 70% owned by the Russian government, controls most of the transmission and distribution in Russia. The grid comprises almost 2 million miles of power lines, 73,000 miles of which are high-voltage cables over 220 kilovolts.”³⁰

District Heating System Precedent Studies

As stated earlier district heating is common in many countries around the world. Once updated, district heating can be a very efficient and environmentally friendly method of creating heat. Reducing greenhouse gas emissions can be accomplished by both improving the efficacies and using alternative fuel sources. Having discussed the major limitations of the Russian district heating network, caused by its age and outdated infrastructure, the next step is to describe an efficient district heating system.

28 US Energy Information Administration, “Russia” Updated November 26, 2013

29 US Energy Information Administration, “Russia” Updated November 26, 2013

30 US Energy Information Administration, “Russia” Updated November 26, 2013

Figure 2.2: Installed Electricity and CHP Capacity in Russia

IEA. 2011. World Energy Outlook 2011 Page 250

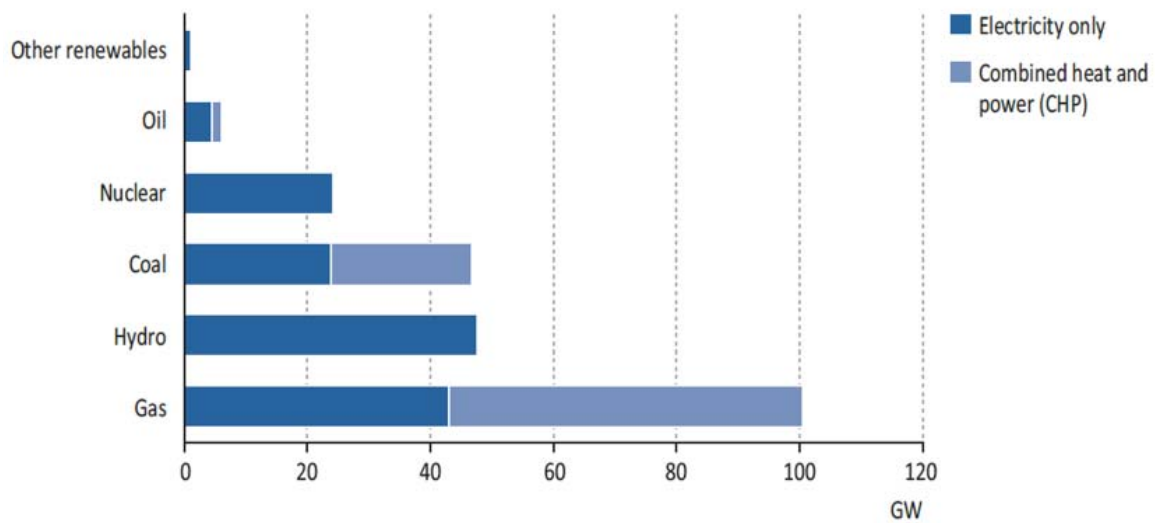
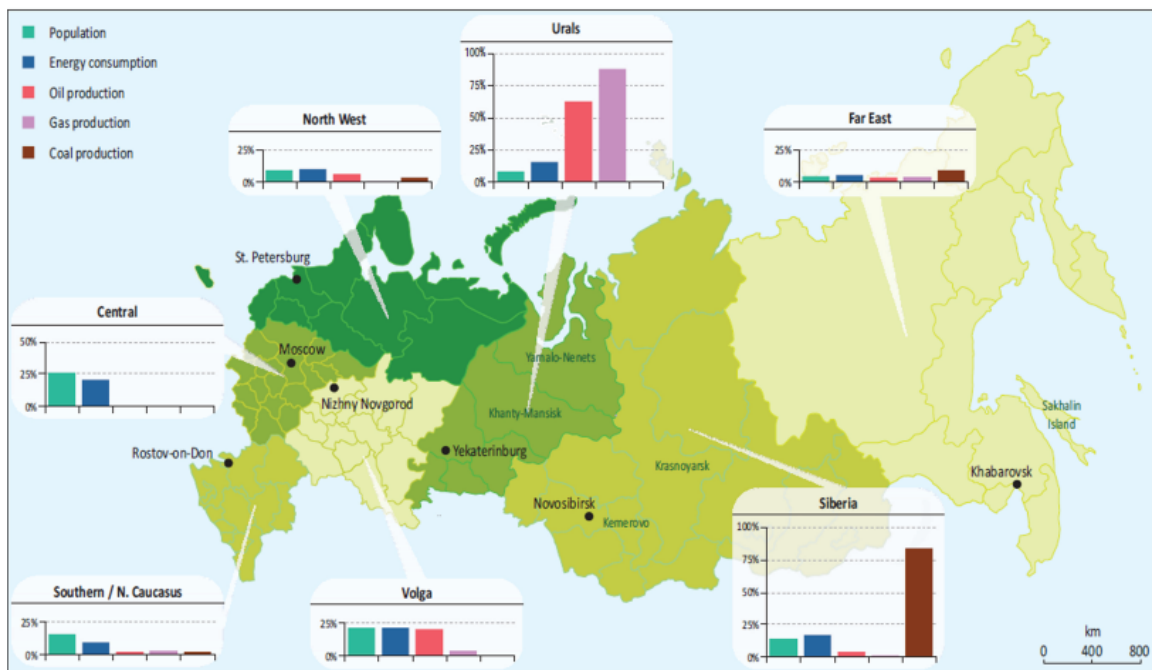


Figure 2.3: Russia's Population, Energy Consumption, and Fossil Fuel Production by Federal District in 2009

IEA. 2011. World Energy Outlook 2011 Page 250



This map is for illustrative purposes and is without prejudice to the status of or sovereignty over any territory covered by this map.

District Heating in Copenhagen

A great example of a system that is operating very efficiently is that of the district heating network in Copenhagen, Denmark. It has been around since the 1920's³¹ and as such is a perfect example of a system that has been well maintained and updated with more efficient technology over the years. In essence, it represents a good contrast to the current Russian system and is an example of how the Russian system would be running if it had been properly maintained and funded over the years.

Copenhagen's District Heating system is a part of the region's district heating system. The heating for their district heating network is created from combined heat and power plants throughout the city. The entire system was created in 1920 and is responsible for providing heat to 98% of the city (the equivalent to approximately 50 million square meters).³² Today it is operated very efficiently and receives ample funding to make major improvements in part due to the city's aging initiative to be the first carbon neutral city in the world by 2025.³³ However, the system did not always receive sufficient funding and attention. In the 1970's, there was a major energy crisis and Denmark began a comprehensive heat planning program involving both municipalities and energy companies. "The 1979 Heat Supply Act enabled municipalities to designate certain areas for district heating and make it mandatory for households to connect to district heating. It was considered a successful initiative, leading to significant energy savings and a reduction in overall dependence on imported oil."³⁴

The Copenhagen District Heating system is a part of a larger metropolitan heating system "that connects four CHP (Combined Heat and Power) plants, three waste incineration plants, and more than 50 peak load boiler plants with more than

31 New York City Global Partners: Innovation and Exchange, "Best Practice: District Heating System: Copenhagen," Updated May 25, 2011

32 New York City Global Partners, "Best Practice: District Heating System: Copenhagen,"

33 New York City Global Partners, "Best Practice: District Heating System: Copenhagen,"

34 New York City Global Partners, "Best Practice: District Heating System: Copenhagen,"

20 distribution companies in one large pool-operated system. Total heat production is approximately 33,000 terajoules per year.”³⁵ The entire energy system is owned and operated by Copenhagen Energy and created a new load management unit called Varmelast.dk which “manages overall optimization of heat production in the region in close cooperation with production plant owners.”³⁶ Figure 2.4 is a map of the district heating network in Copenhagen; the four different regions are highlighted in different colors.

Approximately one-third of Copenhagen’s system is a steam operated system. This was originally designed to provide high temperature heating to portions of the city that required it, such as hospitals and industry. However, Copenhagen is in the process of converting its steam pipelines into water pipelines because water is more efficient and has less heat loss. Copenhagen is constantly improving its district heating system and making it more efficient which is why it is one of the best district heating systems in the world.³⁷ “The conversion to a water-based system will bring about substantial economic benefits due to improved energy efficiency in production and distribution as well as reduced CO2 emissions.”³⁸

In Copenhagen’s desire to continually improve its system, it is also looking at alternatives in energy and heat production. “In 2009, a renovated Unit 1 at Amagerværket (AMV1), owned by Vattenfall, was put into operation, and old less efficient CHP units in the city were shut down. As the first plant in Denmark, AMV1 was subject to a requirement of a minimum percentage of biomass-based CHP production. Thus AMV1 is mainly biomass-fueled, with coal as a backup fuel.”³⁹ This biomass plant runs at approximately 95 percent efficiency and the Danish natural gas boilers run at

35 New York City Global Partners, “Best Practice: District Heating System: Copenhagen,”

36 New York City Global Partners, “Best Practice: District Heating System: Copenhagen,”

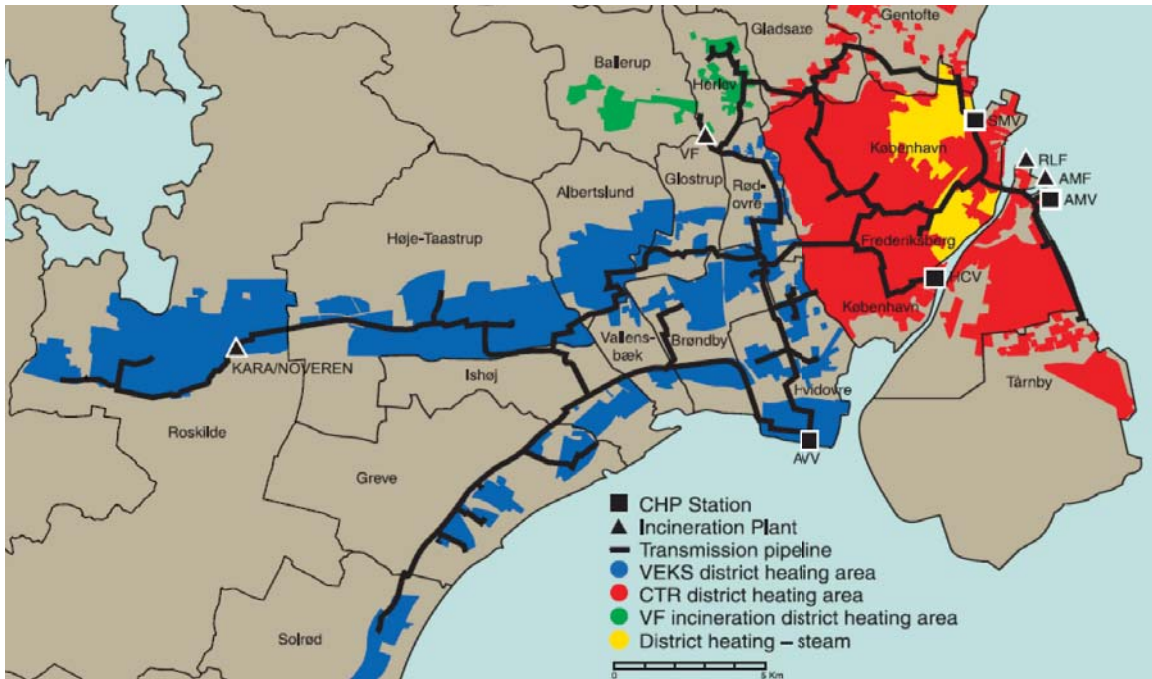
37 New York City Global Partners, “Best Practice: District Heating System: Copenhagen,”

38 New York City Global Partners, “Best Practice: District Heating System: Copenhagen,”

39 New York City Global Partners, “Best Practice: District Heating System: Copenhagen,”

Figure 2.4: Copenhagen District Heating Network Map

http://www.nyc.gov/html/ia/gprb/downloads/pdf/Copenhagen_districtheating.pdf



approximately 85% efficiency.⁴⁰ In addition, Copenhagen created a large scale tunnel, with a diameter exceeding 4 meters, which connects the Amagerværket to the existing steam-based district heating portion of the system.

To understand the efficiency of the district heating network, it is important to understand the cost of heating to the individual residences. “In 2011, the cost of district heating is approximately 50% of the alternative cost of oil for a 130 square meter home having an annual consumption of 18 MWh/year, including energy taxes. Similarly, the cost of district heating is approximately 60% of the alternative cost of natural gas heating for the same home.”⁴¹

Copenhagen is an example of the potential of a district heating network that is properly run. The city is constantly looking for new and more efficient methods of heat production as well as trying to find ways to reduce inefficiencies and waste in heat distribution. Because of these efforts, district heating in Copenhagen is roughly half the price to heat a comparably sized residence with a standard oil boiler equivalent. This was not a system that was created overnight, nor was it a brand new system that had no retrofit expense. The entire system had to be updated and retrofitted over the years. This was made possible, in large part, by new legislation that allowed for funding to be diverted into the energy sector. Today Copenhagen is seeing the return on that investment and has created a truly magnificent district heating system.

District Heating in New York

New York City is home to what could be considered the oldest district heating network. There were smaller networks in place before New York’s system began. However, it is still considered one of the first major heating systems in the world.

40 International Energy Agency. “The International CHP/DHC Collaborative: CHP/DHC Country Score Card Denmark.” Page 6.

41 New York City Global Partners, “Best Practice: District Heating System: Copenhagen,”

New York City's district heating network started in 1877 and was created by Thomas Edison, who began his business with the Edison Electric Illuminating Company of New York in 1870. Then in 1877, Edison created a company called Holly Steam Combination Company (later to be called American District Steam Heat Co.)⁴² "By 1882, Holly, the "father of district steam heating," had been issued 50 patents related to steam heat; he had developed a steam meter and his district steam system was being used in cities across America."⁴³ The system continued to expand throughout the City of New York thanks to legislation changes that allowed for funding the district heating network. "Today, Con Edison operates the largest CHP in the United States. The system contains 105 miles of mains and service pipes, providing steam for heating, hot water, and air conditioning to approximately 1,700 customers in Manhattan."⁴⁴ The city was broken up into 10 heating districts that are still in place today. Figure 2.5 is a map of New York's district heating system as of 2003.

As New York City's district heating network is one of the oldest in the world, it has had to undergo many upgrades. These upgrades have been done to improve both the efficiency and the safety of the system. One upgrade that took place was a 10-year Steam Enhancement Program that was completed in 1999. It cost Con Edison more than 200 million dollars and mainly focused on the replacement of manholes, expansion joints, anchors and fittings. These updates minimized leaks and blowouts and also made the system more environmentally friendly.⁴⁵

One of the downsides to New York City's district heating network is that it is a steam-based system as opposed to the primarily hot water based system in Copenhagen. Hot water has better efficiencies than steam in transportation over long distances (losing only roughly between 5-10% of heat from end to end of the system)⁴⁶ and it is typically

42 "A Brief History on Con Edison: Steam," Consolidated Edison, Inc.

43 "A Brief History on Con Edison: Steam," Consolidated Edison, Inc.

44 "A Brief History on Con Edison: Steam," Consolidated Edison, Inc.

45 District Energy.org. "A Tale of the New York City Steam System." Consolidated Edison, Inc.

46 Ulloa, Priscilla, "Potential for Combined Heat and Power and District Heating and Cooling from Wasteto-Energy

Figure 2.5: New York City District Heating Map, 2003.
 "A Tale of the New York City Steam System." Page 3

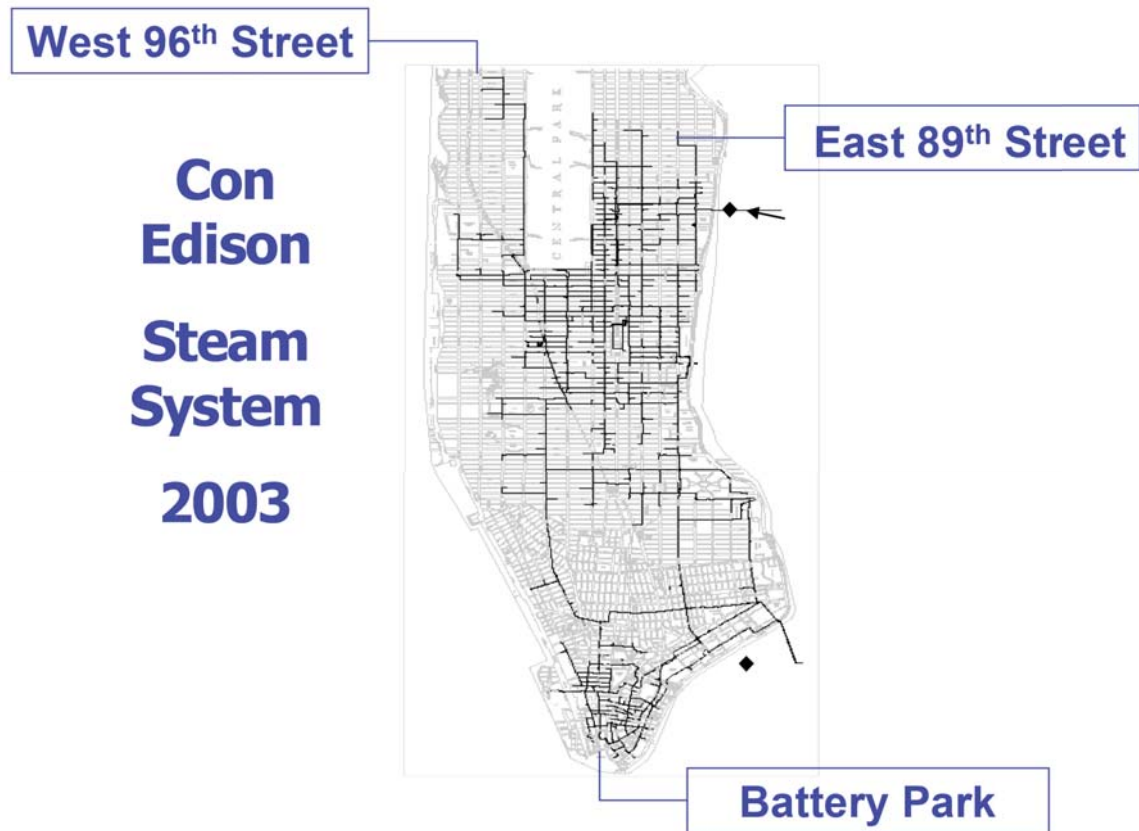
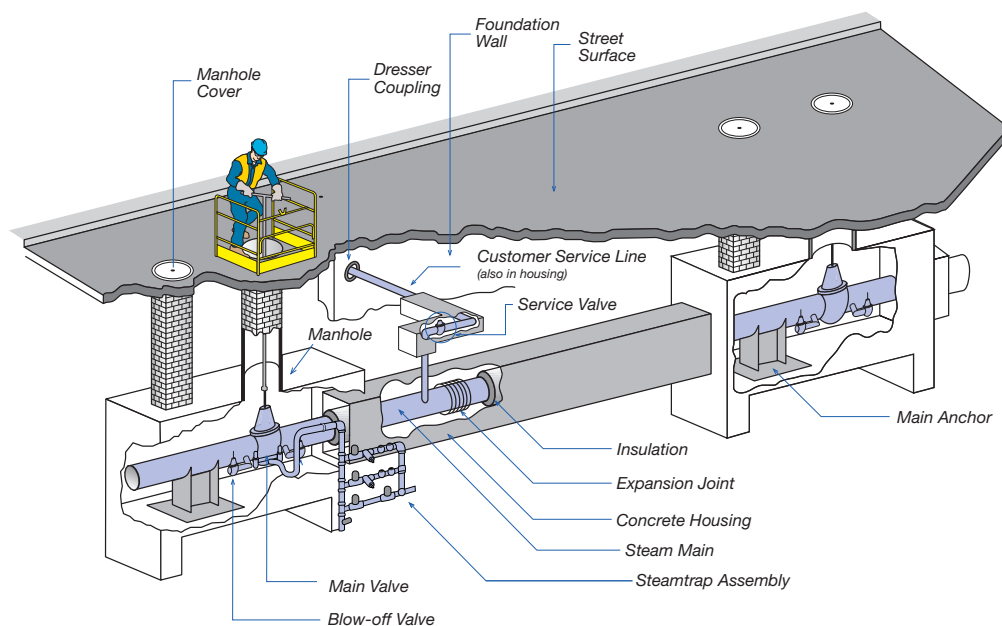


Figure 2.6: Con Edison Steam Distribution Diagram
<http://www.coned.com/>



Steam Distribution System



less expensive to install distribution piping. Steam based piping must be insulated, laid into the “channels and encased in four-foot-by-four-foot concrete jackets, in order to withstand traffic disturbances,”⁴⁷ as the pipes are laid below the streets. New York City’s steam heating system loses a significant amount of energy due to leaks in the system and requires pipes to be updated constantly. Due to the inefficiencies of steam heating many cities in the US are beginning to switch to hot water based heating systems.⁴⁸ Figure 2.6 is a schematic diagram that shows how the New York City steam piping system was built.

Con Edison reported its total losses “end to end” or the total heat loss from leaving the production facility to the furthest location they service in its steam long range plan in 2011. Con Edison stated their total inefficiency of the system at around 60 percent efficient in the winter months.⁴⁹ Con Edison has made plans to improve these efficiencies with a desired efficiency in 2015 of 63 percent efficient. They are planning on improving the insulation in the piping systems as well as updating old outdated pipes that are prone to leaks and blowouts, shown in Figure 2.7. In addition to being less efficient than a hot water district heating system, steam systems are far more deadly. When they fail, they can explode and, in a few instances in New York, have killed people. Part of Con Edison’s long range plan for the city is to create more Combined Heat and Power options in order to improve the overall efficiencies of the system which will result in savings that can be passed directly to the users.

Con Edison’s efficiencies, even if obtained in 2015, would only be about 5 percent better than Russia’s overall efficiency, despite massive upgrades in the New York City’s district heating network. Steam heating, while properly run in New York, is still not as

Facilities in the U.S. – Learning from the Danish Experience,” Department of Earth and Environmental Engineering Fund Foundation of School of Engineering and Applied Science Columbia University, May 2007, Page 19

47 Ulloa, Priscilla, “Potential for Combined Heat and Power and District Heating and Cooling from Wasteto ...” Page 19.

48 Ulloa, Priscilla, “Potential for Combined Heat and Power and District Heating and Cooling from Wasteto ...” Page 19.

49 “Steam Long Range Plan: 2011-2031,” Consolidated Edison, Inc. May 17, 2012, Page 67

efficient as, and is potentially more dangerous than, hot-water systems which are one of the reasons that Copenhagen is switching some of their remaining steam heating system to the more efficient and safer hot water heating system. New York City's district heating network was one of the first district heating systems ever created. It has been well maintained, but is still lagging behind the European model due largely to the inefficiencies in steam and an older outdated piping network that while being maintained and replaced is unable to be as efficient as hot water systems. As many systems in the United States are making the switch to hot water we may see New York do so as well in order to minimize losses.

District Heating Conclusions

District heating when operating correctly should be one of the most efficient heating systems for large scale city heating. However district heating in Russia is so inefficient, that local building heating sources have the potential to be more efficient, and at the same time save the country the massive expense of having to replace 70 percent of the district heating system, a number so large that the country itself must look to private sources to help fund. This is in stark contrast to how well the district heating system could be running as shown in the Copenhagen model. If properly updated district heating is far more efficient than local options however, when not properly maintained over decades the system begins to fail. In addition, being more environmentally conscious is an important consideration as well. A table comparing the Russia district heating system in Volzhsky to New York City and Copenhagen is shown to the in Table 2.1.

However, district heating shortcomings and issues in Russia is just one part of the problem when improving the thermal comfort conditions in Russian social housing. The other side of this issue is dealing with the incredibly low building standards that were present during the massive housing build. These buildings have very low energy

Figure 2.7: Steam Escaping Manhole in New York City
<http://urbanomnibus.net/2014/06/cooling-down-steam-heat-a-retrofit-for-your-radiator/>



Table 2.1: District Heating Comparison

Location	Population of City	Size of System	Piping Used	Primary Fuel Source	Heat Generation	Generation Efficiency	Method of Distribution	Distribution Efficiency	Net Efficiency
Russian District Heating System (Volzhsky)	314,255	57.9 Square Miles	Cast Iron	Natural Gas 66%	CHP Plants	73% (Country Wide)	100% Hot Water	80% (Country Wide)	58%
New York City District Heating System (Manhattan)	1,620,000	305 Square Miles	Cast Iron with Concrete Housing	Natural Gas	Boilers		100% Steam		60%
Copenhagen District Heating System	569,557	34 Square Miles	high density polyethylene	Biomass with Fossil Fuel back up	CHP Biomass with Natural Gas backup	95% , 85%	30% Steam 70% hot water	90-95%	85.50%

efficiency due to their minimal insulation levels and poor construction quality, and therefore demand large amounts of energy to heat. The information gathered in this section emphasizes just how important the build envelope thermal efficiency is. Because Russia has no plan forward on improving the district heating throughout the country, improving the building envelope thermal efficacies will provide substantial improvement in reducing the energy demand on the overall system.

Chapter 3: Building Envelope

Due to the exorbitant expense and massive undertaking required to replace the district heating system in Russia, a more cost effective option would be to improve the thermal insulation of the buildings themselves. This would decrease the demand on the heating system and improve thermal comfort of the buildings. If the buildings have a high enough insulation value then the impact of periodic interruptions in district heating service on the inhabitants of the buildings would be less severe. In order to properly suggest insulation and envelope alternatives to the Russian social housing buildings, we must first understand: how they were constructed; what their current level of thermal insulation is; and how the building code in Russia has evolved to improve conditions today. Once we have a thorough understanding of these factors we can examine possible improvements to the building envelope insulation.

The majority Russian housing stock is old (on average over 50 years old) “about 60% of the multifamily apartment buildings are in need of major capitol repairs”¹ due to the fact that they were made with a 25 year intended lifespan and minimal maintenance since they were constructed. These factors, in conjunction with minimal building standards at the time of construction, have resulted in having a housing supply that consists largely of very old apartments with poor insulation values resulting in a high energy demand to heat them. In this section, we will thoroughly examine the evolution of the Russian energy code and look at some current examples of retrofits in Moscow.

Russian Building Code Evolution

One of the major drawbacks of the buildings constructed during the social

¹ Satu Paiho, Rinat Abdurafikov, Ha Hoang, “Business aspects of energy efficient renovations of Soviet era residential districts” VTT Technical Research Center Finland , Page 7

housing boom was the lack of proper thermal insulation standards in the building code. The buildings were created to be inexpensive and mass produced as quickly as possible, and thermal insulation was overlooked for these reasons. This did not change until 1979 when code requirements were updated to reflect the need for energy conservation in building construction.² Progress was furthered in 1994-1995 with adoption of a new regional code in Moscow entitled “Energy Efficiency in Buildings.”³ “This code introduced requirements for the thermal performance of the building, as well as for heating, domestic hot water, heat supply, electricity, and water supply systems.”⁴ This code was initially adopted only for the city of Moscow. However, after the immense success of the code in Moscow, it was adopted as part of the federal building code in two stages, starting in 1995 and further strengthened in 2000. The first stage of the code doubled the standards for thermal insulation requirements in walls and the second stage tripled the original standards, implementing new standards that are similar to standards used in Sweden and Canada.⁵

The Russian building code has two major standards consisting of federal and local codes. The federal code is called SNiP (Строительные Нормы и Правила) and is the main building code standard in Russia today.⁶ As indicated previously, the code initially had very minimal thermal insulation standards. In fact, during the initial years of the social housing era, the thermal insulation standard was only concerned with keeping the thermal insulation at a level sufficient to prevent moisture accumulation in the interior of the space. As a result, the low thermal insulation standard helped keep the construction costs lower.

Thermal insulation is primarily measured by its R-Value. R-Value is the ability

² Encharter.org, “Energy Efficiency Chapter 5: Progress in Improving Energy Efficiency in Buildings, Appliances and Through District Heating and Cogeneration,” page 74

³ Encharter.org, “Energy Efficiency Chapter 5” page 74.

⁴ Encharter.org, “Energy Efficiency Chapter 5” page 74.

⁵ Encharter.org, “Energy Efficiency Chapter 5” page 74.

⁶ Yu.A Matrosov, L.K. Norford, M.W. Opitz, LN. Butovsky, “Standards for Heating Energy Use in Russian Buildings: A Review and a Report of Recent Progress,” Research Institute of Building Physics, Moscow, Russia and Massachusetts Institute of Technology, Page 214

of a material to resist heat flow. The higher the R-Value, the better the insulation of a given material. The overall thermal resistance of the material is then multiplied by the thickness of that material to give an overall R-value of the insulation being used.

The building code in Russia was broken into three categories based on geographic location and they were given the classification “D”. $D < 4$ was considered the coldest climates; $D > 7$ was considered the warmest climates; and $4 < D < 7$ was considered the middle range climates.⁷ The temperature used to determine these climate ranges was based on the 8 coldest years averaged together over a 50 year period of time to determine the coldest temperatures on record. These classifications determined the wall construction typology and the insulation standards of that wall. In the 1954 SNIP building code, Russia specified that the total R-value of the wall had to be $0.97 \text{ m}^2\text{K/W}$ (IP R-Value of 5.5) in climate $D < 4$ and as low as $0.84 \text{ m}^2\text{K/W}$ (IP R-Value of 4.78) in climate $D > 7$.⁸ Over the years Russia modified this code to make the building envelope more energy efficient. The results of this progression over the period from 1954 to 1993 are shown in the chart in Table 3.1. This represents the changes in the code until the major reforms began in 1994.

After 1995, the building code drastically changed and Russia also created a new form of categorization based on the number of degree days in the heating season, which is the number of days where exterior temperatures are cold enough to require heating the interior space. This created 6 categories of climate classification compared to the original 3 categories. With number one on the table being the warmest climate and six being the coldest. The results of the code changes are shown in Table 3.2 covering the 1995 code change and Table 3.3 covering the 2000 code change.

As you can see from the progression of the building code over time the standards

⁷ Yu.A Matrosov, L.K. Norford, M.W. Opitz, LN. Butovsky, “Standards for Heating Energy Use in Russian Buildings” Page 214

⁸ Yu.A Matrosov, L.K. Norford, M.W. Opitz, LN. Butovsky, “Standards for Heating Energy Use in Russian Buildings” Page 214

Table 3.1:R-Values 1954-1993

"Standards for Heating Energy use in Russian Buildings: A Review and a Report of Recent Progress." Page 216

Metric R-values of Construction Assemblies

Regional Location Type of wall						
Construction	1954-1962	1963-1971	1972-1978	1979-1986	1987-1993	
D<4 (Coldest Degree Locations)	0.97	1.06-1.15		0.96	1.4	1.7
4<D>7	0.93	0.9		0.9	0.9	0.9
D>7 (Warmest Degree Locations)	0.84	0.84		0.84	0.93	0.92
Fenestration(Windows/Doors)				0.34	0.34	0.39

IP R-values of Construction Assemblies

Regional Location Type of wall						
Construction	1954-1962	1963-1971	1972-1978	1979-1986	1987-1993	
D<4 (Coldest Degree Locations)	5.529	6.04-6.55		5.472	7.98	9.69
4<D>7	5.301	5.13		5.13	5.13	5.13
D>7 (Warmest Degree Locations)	4.788	4.788		4.788	5.301	5.244
Fenestration(Windows/Doors)				1.938	1.938	2.223

Table 3.2:R-Values 1995

"Standards for Heating Energy use in Russian Buildings: A Review and a Report of Recent Progress." Page 218

Building Code Amended SNiP 11-3-79(Effective 1995)

Metric R-values of Construction Assemblies

Building Location Typology	Number of Degree Days in the Heating Season (°C d)						
			Walls	Roofing Constructitons (Attics Included)	Floors Above Open Air Spaces	Windows and Balcony Doors	Skylights
	1	2000	1.20	1.80	1.60	0.35	0.25
	2	4000	1.60	2.50	2.20	0.40	0.30
	3	6000	2.00	3.20	2.80	0.45	0.35
	4	8000	2.40	3.90	3.40	0.50	0.40
	5	10000	2.80	4.60	4.00	0.55	0.45
	6	12000	3.20	5.30	4.60	0.60	0.50

IP R-values of Construction Assemblies

Building Location Typology	Number of Degree Days in the Heating Season (°C d)						
			Walls	Roofing Constructitons (Attics Included)	Floors Above Open Air Spaces	Windows and Balcony Doors	Skylights
	1	2000	6.72	10.08	8.96	1.96	1.40
	2	4000	8.96	14.00	12.32	2.24	1.68
	3	6000	11.20	17.92	15.68	2.52	1.96
	4	8000	13.44	21.84	19.04	2.80	2.24
	5	10000	15.68	25.76	22.40	3.08	2.52
	6	12000	17.92	29.68	25.76	3.36	2.80

that were implemented in 1995 and later in 2000, represented the largest improvements overall. The first stage resulted in a reduction in building energy consumption by 20 percent and the second stage resulted in a reduction by an additional 20 percent.⁹ These energy reductions represented drastic steps forward in the building construction standards in Russia. These increased standards revolutionized new construction practices in Russia. However, this same attention to energy efficiency in the new building construction has not yet been resulted in extensive retrofitting of the older buildings that were not constructed to the same energy standards. Russia should endeavor to improve the thermal performance of the building envelope of these older buildings in order to reduce building energy use. As social housing represents the majority of the housing units in the country, one objective of this research document is to research and recommend alternative envelope retrofits to the existing social housing sector that can be used as viable options to improve both the aesthetics and the energy performance of these buildings.

Russian Building Code: As Built Conditions

The Russian building code has taken drastic steps forward in its energy efficiency standards. The standards that were present in the 1950's and 1960's were not only substantially inefficient, but they were not enforced. As such, the thermal insulation of the buildings actually constructed was typically lower than the required code for the insulation standards of the exterior wall construction.

A study conducted in Moscow in the late 1990's assessed the feasibility of retrofitting the existing social housing stock in Moscow. As part of this study, actual U-Values were measured in existing social housing buildings. U-Values are the inverse of R-Values and show the same information in a different form. Tests were conducted in a total of 74 apartments located in 23 different buildings in Zhukovskij, Ryazan,

⁹ Encharter.org, "Energy Efficiency Chapter 5" page74

Table 3.3:R-Values 2000

“Standards for Heating Energy use in Russian Buildings: A Review and a Report of Recent Progress.” Page 218

Building Code Amended SNiP 11-3-79(Effective 2000)

Metric R-values of Construction Assemblies

Building Location Typology	Number of Degree Days in the Heating Season (°C d)		Roofing Construcitons (Attics Included)		Floors Above Open Air Spaces	Windows and Balcony Doors	Skylights
		Walls					
	1	2000	2.10	3.20	2.80	0.35	0.25
	2	4000	2.80	4.20	3.70	0.40	0.30
	3	6000	3.50	5.20	4.60	0.45	0.35
	4	8000	4.20	6.20	5.50	0.50	0.40
	5	10000	4.90	7.20	6.40	0.55	0.45
	6	12000	5.60	8.20	7.30	0.60	0.50

IP R-values of Construction Assemblies

Building Location Typology	Number of Degree Days in the Heating Season (°C d)		Roofing Construcitons (Attics Included)		Floors Above Open Air Spaces	Windows and Balcony Doors	Skylights
			Walls				
	1	2000	11.97	18.24	15.96	2.00	1.43
	2	4000	15.96	23.94	21.09	2.28	1.71
	3	6000	19.95	29.64	26.22	2.57	2.00
	4	8000	23.94	35.34	31.35	2.85	2.28
	5	10000	27.93	41.04	36.48	3.14	2.57
	6	12000	31.92	46.74	41.61	3.42	2.85

Table 3.4:U-Value and R-Value as Built Test Results

“Russian Apartment Building Thermal Response Models for Retrofit Selection and Verification.” Page 3.6.

U-Value Test of Existing Social Housing Buildings

Construction Type and Location	U-Value	Standard Deviation	Metric R- Value	R-Value (IP Units)	Metric Standard Deviation	R-Value (IP Units)	Metric R- Value with Air Flim	R-Value (IP Units)	Metric Air Film Difference of R- Value	R-Value (IP Units)
Orenburg Panel	2.76	0.79	0.362	1.82	1.266	7.22	0.512	2.92	0.15	0.86
Petrozavodsk Gable Panel	1.31	0.96	0.763	4.35	1.042	5.94	0.913	5.20	0.15	0.86
Petrozavodsk Panel	2.66	0.76	0.376	2.14	1.316	7.50	0.526	3.00	0.15	0.86
Ryazan Panel	3.81	1.14	0.262	1.49	0.877	5.00	0.412	2.35	0.15	0.86
Zhukovskij	1.95	0.46	0.513	2.92	2.174	12.39	0.663	3.78	0.15	0.86
Orenburg Floor	3.24	3.64	0.309	1.76	0.275	1.57	0.635	3.62	0.326	1.86
Ryazan Floor	19.62	1.82	0.051	0.29	0.549	3.13	0.377	2.15	0.326	1.86
Orenburg Attic	22.64	6.06	0.044	0.25	0.165	0.94	0.26	1.48	0.216	1.23
Petrozavodsk Attic	18.75	NA	0.053	0.30	NA		0.269	1.53	0.216	1.23

Petrozavodsk, and Orenburg.¹⁰ These results have been categorized in Table 3.4 by wall construction type and location with an average U-Value, R-value and respective standard deviations of these results.

The standard deviations are quite high due to the inaccuracies of the actual construction of each building. However, the mean R-Values for the buildings showed that they were constructed with thermal insulation 37 to 76 percent of the standard based on the Russian building code. In essence, the code was already far too relaxed and the actual construction was not even built to that minimum standard.

When reading the chart, there is a category called R-Value with air film. While it is unknown if the standard was to not include an air film in the original construction, as part of the test, an air film was added to the walls on the exterior and interior of the building in order to assess one potential retrofit option and its effectiveness on the insulation properties of the buildings. The air film made minimal difference on the exterior walls but had far greater improvement on the floor and roof areas. This was a simple retrofit option that was easy to test and at the time set a baseline for future retrofit options that could be considered when retrofitting the social housing buildings in the city as a whole.

Social Housing Retrofit in Moscow

The concept of retrofitting and updating the building envelopes of the older social housing buildings in Russia is not a new concept. It has been already attempted in Moscow. Moscow conducted feasibility studies on upgrading the social housing buildings. Testing of existing buildings was used to inform the policy makers regarding the most appropriate upgrades. Today Moscow has already undergone extensive renovation and upgrades. The city has looked at three major options for its upgrade

10 Peter Armstrong, Jim Dirks, Ray Reilly, Bill Currie, Ron Nesse. Oleg Komarov. Boris Nekrasov, "Russian Apartment Building Thermal Response Models for Retrofit Selection and Verification," American Council for Energy Efficient Economy, Page 3.6

process. The first was creating new housing in the city to help meet the housing demand; the second was retrofitting existing buildings; and the third was replacement or tearing down the existing social housing buildings and constructing new buildings.¹¹

Due to a combination of political reasons, Russia had determined, in the late 90's, that the best improvements will come from replacement and new housing stock rather than upgrading the other outdated buildings throughout the country. Although Russia may have favored demolition and replacement over refurbishment and retrofit in Moscow, there has still been a substantial portion of the buildings that have been retrofitted giving good precedent studies that can be used to create better alternatives for retrofits in other cities. Russia is constantly looking for better options because the situation is so unacceptable across the country. As of 2003, "Restoration of 5-storey shabby and dilapidated buildings was carried out. As a result 15,500 families from 250 residential structures with a floor area of 670,200 square meters were resettled."¹²

Moscow Retrofit Precedent

In 2014, a thorough study of building retrofits was conducted in Moscow by VTT Technical Research Center of in Finland¹³, to determine the cost feasibility of applying these construction upgrades to Russia's entire social housing supply. The location of this housing study took place in the 4th Microrayon (apartment block) of Zelenograd, Moscow (longitude 37° east and latitude 55° north). Zelenograd is located about 35 km to the north-west from Moscow City Centre and is approximately 1 km × 0.5 km in size. The buildings here were constructed during the 1960's-1970's.¹⁴ There were several sizes of buildings selected for study. The results are shown in Table 3.5 for building

11 Alexander Krashenninokov, "Urban Slums Report: The Case of Moscow, Russia," Moscow Architectural Institute, Page 18

12 "Alexander Krashenninokov, "Urban Slums Report:" Page 18

13 Satu Paiho, Rinat Abdurafikov, Ha Hoang, "Business Aspects of Energy Efficient Renovations of Soviet era Residential Districts" VTT Technical Research Center Finland 2014." Page 16

14 Satu Paiho, Rinat Abdurafikov, Ha Hoang, "Business Aspects of Energy Efficient Renovations" Page 16

series 11-18 which is a 12 story building with 4911 square meters of living space and 207 residents. It was estimated that the average occupancy of each unit in the building selected was 2.7 people per flat.¹⁵ In total 13,800 residents were included in this renovation test and a total of 327,600 square meters of living space was improved.¹⁶

The buildings in this section were then tested to record current insulation levels and then assigned one of three levels of renovation. The first or “basic” level only utilized simple relatively affordable materials that were easy to install. Part of this renovation included basic improvements to the building to bring it back to original construction levels, including addressing sealant leaks, building cracks, etc. that were a result of the age of the building.¹⁷

The intermediate level of retrofit was called the Improved Renovation Level and added more thermal insulation to building walls and roofs bringing them to current code standards for new building construction. In addition, it introduced mechanical exhaust and ventilation improvements of the building’s systems to ensure sufficient air exchange rates in the apartments.¹⁸

The highest level of retrofit was called the Advanced Level of Improvement and it increased the R-value of the wall to almost double what was required by the building code. This level was created as a maximum potential possibility while still being considered to be realistic in a financial sense.¹⁹ In Table 3.5, there is a breakdown of the proposed improvements to buildings, their relative R-value improvements and the cost per square meter for the retrofits. In addition, all the other improvements that were made on the building and its systems are included in the table and total cost of the renovations for each level of retrofit is provided as well.

15 Satu Paiho, Rinat Abdurafikov, Ha Hoang, “Business Aspects of Energy Efficient Renovations” Page 16

16 Satu Paiho, Rinat Abdurafikov, Ha Hoang, “Business Aspects of Energy Efficient Renovations” Page 16

17 Satu Paiho, Rinat Abdurafikov, Ha Hoang, “Business Aspects of Energy Efficient Renovations” Page 17

18 Satu Paiho, Rinat Abdurafikov, Ha Hoang, “Business Aspects of Energy Efficient Renovations” Page 17

19 Satu Paiho, Rinat Abdurafikov, Ha Hoang, “Business Aspects of Energy Efficient Renovations” Page 17

Table 3.5: Moscow Social Housing Retrofit Test 2014

Metric to IP Conversion = Metric R-value x 5.7

Paiho, Satu. Rinat Abdurafikov, Ha Hoang. "Business aspects of energy efficient renovations of Soviet era residential districts" VTT Technical Research Center Finland 2014

	Current		Basic				Improved				Advanced				Current SNiP Code	
	R-Value	Improvement Measure	Cost/m2 of living area [€/m2]	New IP R-Value	New SI R-Value	Improvement Measure	Cost/m2 of living area [€/m2]	New IP R-Value	New SI R-Value	Improvement Measure	Cost/m2 of living area [€/m2]	New IP R-Value	New SI R-Value	IP R-Value	SI R-Value	
Exterior Walls	IP	IS	Sealing of joints, repair of external walls, painting and plastering	7.24		Sealing of external walls seams	7.31			Sealing of external walls seams	7.31					
	5.12	0.9	Thermal insulation of external walls 30 mm of mineral wool (MW) and/or polystyrene (PS), and plastering	40.76		Thermal insulation of external walls (100 mm MW/PS) and plastering	47.61			Thermal insulation as prefabricated elements or in-situ (200-300 mm MW/PS) and plastering	62.75					
	SUM			51	11.4	2	54.92	16.76	2.94		70.04	38	6.66	19.95	3.5	
Windows and Doors	IP	IS	Installation of new windows	9.45		Installation of new windows	9.45			Installation of new windows	9.45					
	1.71	0.3	3-pane windows	15.07		Energy efficient 3-pane windows	19.54			Energy efficient 3-pane. 2 low-e glass panes windows	21.32					
	SUM			24.52	3.08	0.54	29	3.76	0.66		30.78	5.7	1	2.57	0.45	
Upper Ceiling	IP	IS	Repair of water insulation membrane, roof slopes for drainage	0.73		Repair of water insulation membrane, roof slopes for drainage	0.73			Repair of water insulation membrane, roof slopes for drainage	0.73					
	5.1	0.9	Thermal insulation 100 mm PS	1.59		Thermal insulation 100 mm PS	1.59			Thermal insulation 300 mm PS	3.18					
	SUM			2.32	22.8	4	2.32	23.71	4.16		3.91	38	6.66	29.64	5.2	
Basement	IP	IS	Thermal insulation 100 mm PS to basement ceiling	6.92		Add extra thermal insulation 100 mm PS to basement ceiling	6.92			2 Add extra thermal insulation 300 mm PS to basement ceiling	8.27					
	5.1	0.9	Soil removal and repair of asphalt strip protecting the foundation from penetration of surface water	0.39		Thermal insulation of basement walls 100 mm PS and plastering	2.87			7 Thermal insulation of basement walls 300 mm PS and plastering	3.43					
	SUM			7.31	x		9.79	x			11.69	x				
Ventilation						Mechanical exhaust ventilation with constant pressure regulation	1.53			Mechanical demand-controlled incoming and exhaust air ventilation with air-to-air heat recovery	6.62					
			Use existing concrete block-based ventilation routes of natural ventilation, cleaning and disinfection	0.86		Use existing concrete block-based ventilation routes of natural ventilation to install new sealed ducts	8.71			Use existing concrete block-based ventilation routes of natural ventilation to install new sealed ducts	8.71					
										Inlet ducts are embedded in the inner surface of the thick insulation of outer walls	15.43					
	SUM			0.86			10.23				30.75					

	Current		Basic				Improved				Advanced				Current SNI Code	
	R-Value	Improvement Measure	Cost/m ² of living area [€/m ²]	New IP R-Value	New SI R-Value	Improvement Measure	Cost/m ² of living area [€/m ²]	New IP R-Value	New R-Value	Improvement Measure	Cost/m ² of living area [€/m ²]	New IP R-Value	New R-Value	IP R-Value	SI R-Value	
Heating System		Automated space heating system control unit	1.07			Building specific heating substation	2.55			Building specific heating substation	2.55					
		Installation of balancing valves in riser pipes of heating system	0.6			Installation of balancing valves in riser pipes of heating system	0.6			0 Installation of balancing valves in riser pipes of heating system	0.6					
						Installation thermostat valves on radiators	3.04			Installation thermostat valves on radiators	3.04					
		Replacement of pipes and thermal insulation	5.34			Replacement of pipes and thermal insulation	5.34			Replacement of pipes and thermal insulation	5.34					
	SUM		7.01				11.52				11.52					
Water and Wastewater		Repair of cold and hot water supply pipes, water pressure regulator, repair of building's sewage system	0.82			Repair of cold and hot water supply pipes, water pressure regulator, repair of building's sewage system	0.82			Repair of cold and hot water supply pipes, water pressure regulator, repair of building's sewage system	1.49					
	SUM		0.82				0.82				1.49					
Electricity		Replacement of building equipment with energy efficient. Energy-efficient lamps to common areas	0.06			Replacement of building equipment with energy efficient. Energy-efficient lamps to common areas	0.06			Replacement of building equipment with energy efficient. Energy-efficient lamps to common areas	0.06					
		Replacement of worn out inbuilding electrical networks and main switchgear	4.8			Replacement of worn out inbuilding electrical networks and main switchgear	4.8			Replacement of worn out inbuilding electrical networks and main switchgear	4.8					
		Replacement of elevators	12.98			Replacement of elevators	12.98			Replacement of elevators	12.98					
						Occupancy sensors in common areas	4.8			Occupancy sensors in common areas	4.8					
	SUM		17.84				22.64				22.64					
Gas		Repairing of pipes and devices	0.24			Repairing of pipes and devices	0.24			Repairing of pipes and devices	0.24					
	SUM		0.24				0.24				0.24					
Metering		Apartment metering (electricity and water)	3.29			Apartment metering (electricity and water)	3.29			Apartment metering (electricity and water)	3.29					
						Monitoring (regular check-up)	0			Smart metering	5.13					
	SUM		3.29				3.29				8.42					
Total Cost			111.92				141.48				183.06					
Total Cost in Dollars Per m ²			\$148.85				\$188.17				\$243.47					

Each option of retrofit, (basic, intermediate, advanced) involved improvements in addition to the insulation of the external façade; such as improving ventilation systems, sealant replacement, etc. These improvements collectively enhanced the overall performance of the building and provide a measure for comparison of alternative potential retrofits for a social housing building in Russia. The overall cost of each level is broken into an individual cost as well as a total cost per square meter of building area. The cost for the basic level was 111.92 euro's per square meter (\$148.85) with a building area of 4,911 square meters²⁰ for this particular building test. This would result in a total cost for the building renovation of 549,639 euros or around \$731,000 in the event this was the primary retrofit selected.²¹ For the intermediate level of retrofit, the cost was 141.48 euros per square meter (\$187.63) which would result in a total cost for the building renovation of 694,808 euros or \$924,095 if all units received this level of retrofit. The advanced renovation cost was 183.06 euros per square meter (\$243.46) which would result in a total retrofit expense of 899,000 euros or \$1,195,680 if it was the retrofit option selected for all the buildings in the test. The estimated conversion from euro's to dollars was based on the average exchange rate of 1.32 Euros to a Dollar in 2014.

This represents a substantial financial investment in order to maximize the efficiency of each building. The investigators determined that the advanced level of upgrade in each area of the building was necessary in order to make the retrofit worthwhile based on both financial and efficiency standards. Prior to this investigation Russia had determined after performing approximately 250 retrofits of the smaller 5-story buildings in Fily Davidkovo, (a housing district chosen as a retrofit, replacement and new development area in Moscow) that replacement was more desirable then retrofitting as stated earlier.²² This study by VTT Technical was conducted almost 10

20 Satu Paiho, Rinat Abdurafikov, Ha Hoang, "Business Aspects of Energy Efficient Renovations" Page 17, Page 41-43 and Page 18

21 "Historical Exchange Rates," OANDA Corporations, 1996-2015

22 Alexander Krashenninokov, "Urban Slums Report" Page 19

years after Russia had made this determination that replacement was better than retrofit and the study was conducted in an effort to give Russia more options for retrofits which could potentially minimize the need for building replacements in Russia.

In addition to retrofitting the buildings in this study by VTT Technical the district heating system upgrades were investigated as well. Costs were estimated and calculated for each district or apartment block. Each district or microrayon was typically serviced by a single substation and then lines would extend outward in a radial fashion to the surrounding apartment buildings. Improvements to the district heating network included upgrades to the piping, substation, as well as updates to the sewer, water and electrical distribution systems. The total cost of the district improvement was categorized based on a price per square meter of built area or living space in the district. This was then broken down into individual building costs for the updates. The total cost of district heating improvements was 63,708 euros or \$84,731 and the cost of all upgrades to the district system including water, sewer and electrical was 217,612 euros or \$289,423.

The district system upgrades also included the replacement of power production with photovoltaics, which may or may not be the best option for improving the efficiency of the power system as most photovoltaic systems are very inefficient and are able to capture at best 24.2% of the total solar power touching the surface of the panels.²³ These power system upgrades were part of two additional levels of upgrade that were referred to as Advanced + and Advanced ++. Advanced plus upgrades involved the use of geothermal heating pumps for the heat supply and photovoltaics to supplement the electricity demand.²⁴ The Advanced double plus used solar thermal collectors mounted on the roofs of the buildings to handle the heating supply. In both of these solutions, the cost of updating the district heating supply was removed. The building cost of

23 "Solar Efficiency Records," PVEducation.org, Visited February 15, 2015

24 Satu Paiho, Rinat Abdurafikov, Ha Hoang, "Business aspects of energy efficient renovations" Page 45

these improvements in the advanced plus option was 23.82 euros per meter squared for the geothermal heat pump and 14.9 euros per meter squared for the solar electric generation.²⁵ That is a total cost of 190,153 euros or \$252,904 for the heat generation and a total cost for the utility upgrades of 344,057 euros or \$457,595; the advanced double plus would add 13.7 euros per square meter to handle the entire heating demand.²⁶ This would make the total for the renovation of the utilities of the building of 411,337 euros or \$547,079.

Depending on the level of retrofit desired, the grand total of the cost could be as high as 1,310,337 euros or \$1,742,748 for each building for all the upgrades or a total cost per square meter of 266.82 euros or \$354.87. A less expensive option such as the intermediate level of retrofit would still enable the project the minimum R-Values required by current Russian SNIIP federal building codes. This was just a test conducted in one microdistrict in Moscow, no additional buildings have been renovated as a result of this test yet. The retrofits while very thorough are still a little too expensive for the government to do throughout the rest of the country.

Retrofit Issues

As stated earlier in 2003, 250 apartment buildings were renovated in Moscow. Initially Moscow favored replacement rather than retrofitting their social housing developments. However, the Russians discovered that the cost of replacement was far too great. Their housing plan in 2003 to replace 50 million square meters of old social housing in the country would have cost around 5.161 billion US dollars which today would be over \$7 billion. Russia determined that replacement was not financially possible and left updates and repairs in the hands of the individual apartment owners.²⁷

25 Satu Paiho, Rinat Abdurafikov, Ha Hoang, "Business Aspects of Energy Efficient Renovations" Page 46

26 Satu Paiho, Rinat Abdurafikov, Ha Hoang, "Business Aspects of Energy Efficient Renovations" Page 46

27 "Urban Slums Report: The Case of Moscow, Russia." Page 19.

Figure 3.1: Completed Retrofit
<https://khrushchevki.wordpress.com/category/microrayon-2/>



Figure 3.2: Non Upgraded Building Next to Completed Retrofit
<https://khrushchevki.wordpress.com/category/microrayon-2/>



The new construction cost of housing in 2012 in Moscow was \$2600 per square meter and just in that year was estimated to increase another 10-15 percent.²⁸ Every year since 2012 Moscow has expecting rises in the new housing construction cost. \$2600 per square meter²⁹ on a new apartment of 70 square meters (which is the size of the current typical 2 bedroom unit in the 9-story prefabricated apartment building) would be \$182,000 per unit. This price per new apartment unit however, did not stop Russia from replacing these units in Moscow where the vast majority of the housing stock has been replaced by the end of 2015. However, a price tag of this amount would make new apartments an unrealistic expense in the rest of the country and even in Moscow, many owners found themselves unable to afford the new prices. The 2014 Housing retrofit study was intended to help Moscow and the rest of Russia consider other options.

One complication in Moscow is that, as of 2009 74.4% of the housing stock was privately owned which puts greater responsibility on the apartment owners to finance the upgrades. This is also complicated by the fact that individual owners cannot choose to upgrade their units because they are part of a collective group in a building that typically has some form of owners association that must vote on matters such as upgrading the thermal efficiency. The challenge with this is not all owners may be in the financial position to pay for the upgrades which limits the ability to move forward for those who are interested in doing so.³⁰

The 1992 privatization of apartment buildings law requires the government as the previous owners of the buildings to carry out capitol repairs. However, most of the provisions that would call for building improvements are complicated. Furthermore residents are “typically poorly informed, get confused by the mass media and often believe that the responsibility of carrying out capitol repairs in the apartment building

28 Yulia Ponomareva, “Moscow Expansion Leaves Developers in Limbo” The Moscow News, May 7, 2012

29 Yulia Ponomareva, “Moscow Expansion Leaves Developers in Limbo”

30 Satu Paiho, Rinat Abdurafikov, Ha Hoang, “Business aspects of energy efficient renovations” Page 55

Figure 3.3: Alternative Completed Retrofit
<https://khrushchevki.wordpress.com/category/microrayon-2/>



rest with the local authorities.”³¹ In addition, most residents are not a part of the homeowners associations and those who are, have limited financing options available to them.

Loans to Housing Associations have been deemed by most Russian banks as an unreliable investment due to the fact that the individuals in charge of the associations typically change every 5 years and maintaining accountability for long term loans is difficult. In addition, Housing Associations “may be liquidated by a general meeting without extension of liabilities onto the buildings residents.”³² This makes banks very uneasy about having large loans with the associations of these buildings. The high cost of retrofits and the challenges of getting financing make it difficult to undertake any form of retrofit.

In addition to the financial limitations to the retrofit, the proposed VTT Technical retrofit process uses a plaster finish coat as well as mineral wool for thermal insulation improvements. While this is able to attain the R-values desired by building code it has several areas for improvement. Major issues with the retrofit include the installation time and expense because the plaster coat is more labor intensive than a prefabricated retrofit option. There are cost effective benefits to a prefabricated option that takes into account the prefabricated nature of the buildings themselves.

Summary of Retrofit Case Study

Financing has always been a limiting factor for retrofits of buildings in any country. A 2014 retrofit study by released by VTT Technical served as a starting point for retrofits in Russia. VTT Technical concluded that individual retrofits will be difficult to self-fund because Russian homeowners associations have difficulty obtaining funding. This is compounded by the fact that owners have to vote on capital improvements

31 Satu Paiho, Rinat Abdurafikov, Ha Hoang, “Business Aspects of Energy Efficient Renovations” Page 55

32 Satu Paiho, Rinat Abdurafikov, Ha Hoang, “Business Aspects of Energy Efficient Renovations” Page 55

of that scale. With Russia providing minimal if any financial support to smaller cities the notion of a full building retrofit becomes rather dubious. Notwithstanding to the financial limitations, the building retrofit options offered by VTT Technical have substantial areas of improvement in both the ease of installation, long term maintenance, sustainability, potential energy efficiency and even aesthetic appeal.

Chapter4: Site Location and Analysis

Now that we have an understanding of the Russian building code and attempted retrofits in Moscow, we will examine the existing building condition in Volzhsky in order to properly assess appropriate retrofit options. As Volzhsky is further south than Moscow, it has a substantially different microclimate and consistently the building construction and thermal requirements are very different than they are in Moscow. Having an understanding of the climate conditions and site conditions in Volzhsky is an essential prerequisite to formulating a proper retrofit solution.

In this section we will cover: a brief history of the city of Volzhsky, its district heating and power system, specific building components and construction of the city's buildings, detailed site and climatic analysis, and financial conditions of the current occupants. This will enable us to make a more appropriate retrofit option for the residents of the city of Volzhsky.

History of Volzhsky

Volzhsky got its start because of the construction of a Hydroelectric power plant in 1950-1961 that the city was rebuilt.¹ "The construction of Stalingrad power station was the reason of forming of a new settlement in Verkhnyaya, Akhtuba. The builders were accommodated in the houses of the settlement dwellers. The construction management was also transferred there from Stalingrad."² The name Volzhsky was registered with the settlement in 1952 and at that time had a population of 10,000 and it became an official city in 1954. At the date of completion of the dam in 1961, the population was approximately 30,000. The majority of this housing boom was due to

¹ Russian Trek.org, "Volzhsky City, Russia"

² Russian Trek.org, "Volzhsky"

the large labor force that was brought in to rebuild the city and build the dam. From that point forward, the population expanded rapidly due to the economics of the city.

“Volzhsky is a large industrial center of the Lower Volga area. Main industries are as follows: chemical, ferrous metallurgy, power engineering, machine-building and food industry. Plants of chemical industry make the city one of the largest centers of this industry in Europe.”³ Volzhsky’s industry is not the only thing that sets it apart. It is considered to be one of the greenest or most vegetated cities in Russia, partially due to the fact that when the city was conceived in 1950, there was a desired goal of protecting it from sandstorms. As a result, the city has substantial green landscape throughout. This in conjunction with the use of hydropower as the main form of electricity generation, makes the city’s utility systems very environmentally friendly.

Housing in Volzhsky

Volzhsky, like every other city in Russia, has a large Social Housing block. Due to the age of the city, the big housing boom occurred after the Khrushchev era. The Khrushchev era ended in 1964 and by that time, the prevailing style of housing had changed toward a taller building type. However, there was a considerable repetition of housing in the city as was the case in many other cities across Russia. In Volzhsky, there was a massive population growth that occurred from 1960-1990. During this time, the city went from approximately 30,000 to 268,842 inhabitants according to the 1989 Soviet Census. Population growth during this time was explosive averaging an increase of 7900 new residents every year. In order to keep up with the demand for new housing, the city mass produced social housing projects.

District Heating and Electricity in Volzhsky

The main electricity utility company in Volzhsky is Lukoil. Lukoil is a relatively

³ Russian Trek.org, “Volzhsky”

Location

- Volzhsky, Russia
- On the east bank of the Volga River in Volgograd Oblast (Province)
- 20 Kilometers Northeast of the city of Volgograd, Russia
- Geographic Location: 48.8056° N, 44.7417° E
- Similar Latitude Locations:
 - o United States: Washington, Montana, North Dakota, Minnesota, Maine
 - o Europe: France, Germany, Austria, Hungary, Lower Ukraine
- Population: 314,255



large oil production company in Russia that is currently responsible for 2.1% of the world's total oil production and 16.5% of Russia's oil production.⁴ Lukoil has been a more progressive oil producer with a desire to make its power sector more environmentally friendly, using both hydroelectric and wind generation power.⁵ While Lukoil may only be responsible for 16.5% of total oil production in Russia, it is the largest privately owned oil company in the country.

Lukoil purchased the rights to the power production in the greater Volgograd area in 2009, converting the utilities from a public to private entity.⁶ Currently, there are two main forms of electricity production in Volzhsky: the hydroelectric power plant and two combined heat and power plants, which provide the heat for the district heating system. There is an additional combined heat and power plant in Volgograd. Figure 4.1 is a map of the utilities that were purchased by Lukoil in 2009. The map includes some basic power and heat statistics for the greater Volgograd area.

As part of the acquisition and restructuring of the heat and power in the area, Lukoil created a new sector of its company called Lukoil Heating Transport Company which manages the heating systems of Volzhsky as well as Kamishin and Astrakhan.⁷ As of 2009, the electricity production was 3.245 billion kilowatt-hours and heat generation was 6.544 million Gcal for the Volgograd Area.⁸ Figure 4.2 is a map of the district heating and power supply of Volgograd and Volzhsky. This map shows the layout of the power and heating utilities operated by Lukoil. Volzhsky is on the right hand side of the map indicated by the black outline.

Building Construction Analysis

Volzhsky's main construction period occurred between the late 1950's and

4 Lukoil: Oil Company, "Power Production"

5 Lukoil: Oil Company, "Power Production"

6 Lukoil: Oil Company, "Power Production: Fact Book 2010"

7 Lukoil: Oil Company, "Power Production: Fact Book 2010"

8 Lukoil: Oil Company, "Power Production: Fact Book 2010"

Figure 4.1: Map of Acquired Utilities by Lukoil

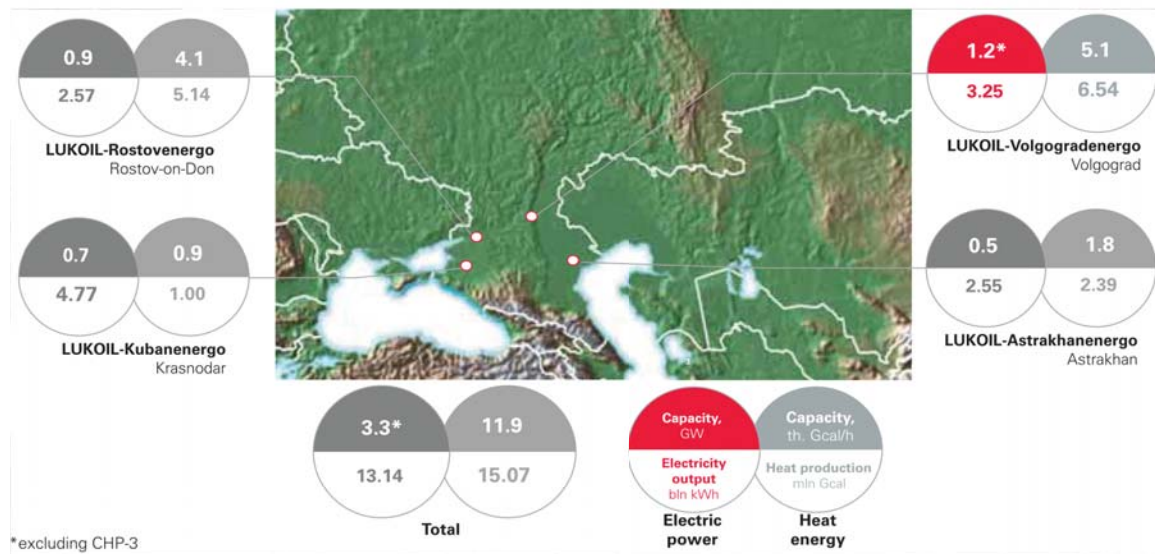
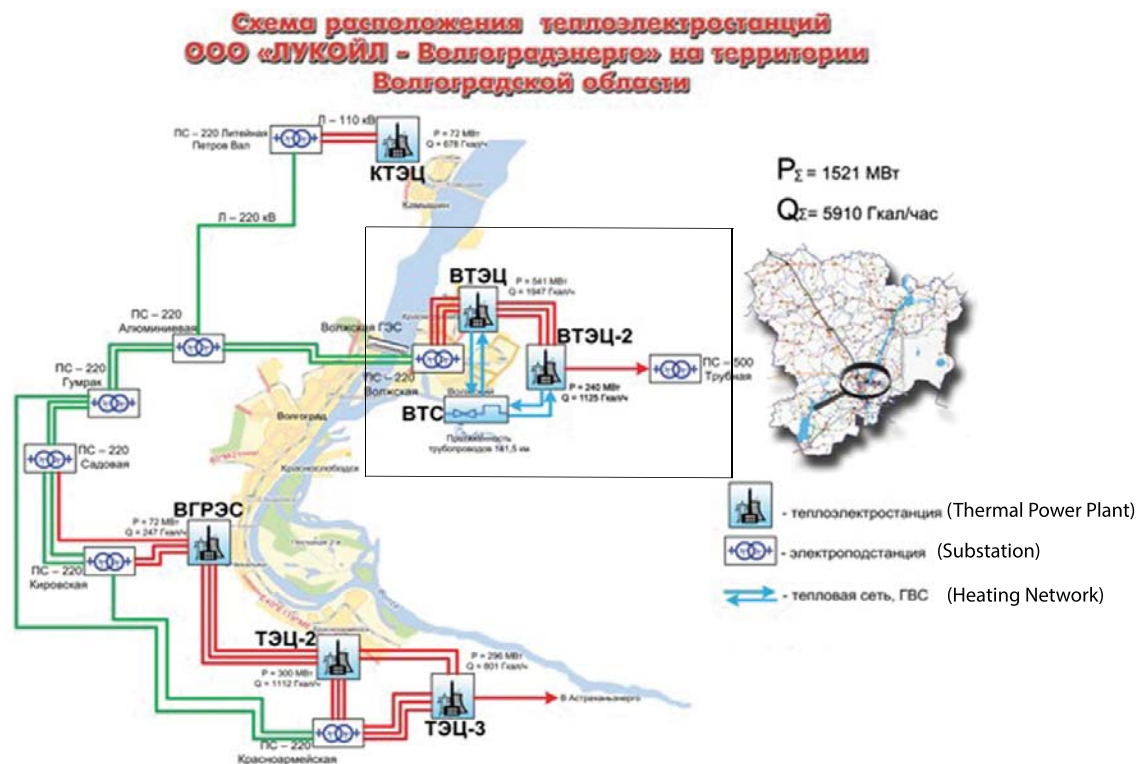
http://www.lukoil.com/materials/images/Power_Generation/FB_2010_eng.pdf


Figure 4.2: District Heating Map of Volzhsky

http://www.volgogradenergo.lukoil.com/main/static.asp?art_id=2100


the early 1970's with two main social housing construction typologies. Prior to the early 1960's, the houses constructed would have been the 5-story krushchyovka style. However as discussed earlier, after the early 1960's the housing style changed to increase density in some Russian cities. Volzhsky has many 9-story apartment buildings. The main construction difference between these two building types is the alteration of the main circulation to include a small elevator.

Over the years, some subtle changes occurred to the design, the overall size of the balconies the general layout, and some exterior variations. However, the general design concept stayed the same: precast concrete panel construction. There were variations in the dimensions of the panels. However, most of the time these variations were necessary to create a 2 to 1 ratio for length vs. width. Figure 4.3 is a chart that shows some typical panel dimensions depending on desired function and building type.⁹ In addition, Figure 4.4 shows the exterior panels being constructed and manufactured prior to installation. There were some subtle ranges in the width and height. However, each building plan would typically stick to one typology.

Even though the chart in Figure 4.3 breaks down many different subtle variations, most of the building panels can be broken into just a few categories. In the 9-story buildings, the typical wall panel dimension was 300 cm x 270 cm¹⁰ while in the 5-story building typical wall panel fell into the 270 cm x 270 cm dimension.¹¹ In figure 4.5, 4.6, 4.7 and 4.8 are the typical floor plans for both the 9-story and 5-story building typologies in Volzhsky. I have included two alternate floor layouts for each building typology, although in actuality, there were many more variances in the interior floor plan layout. However, the external structure and window placement remained the same regardless of the floor plan layout. In essence the building looked the same from the outside

⁹ Soviet Union "Arkhitektura SSSR: 1960," no. 6, page 46

¹⁰ Soviet Union, "Arkhitektura SSSR: 1963," no. 1, Page 14

¹¹ Soviet Union, "Arkhitektura SSSR: 1964," no. 4, Page 10

Figure 4.3: Table of Typical Wall Panels
Soviet Union, "Arkhitectura SSSR: 1960." no. 6, page 46.

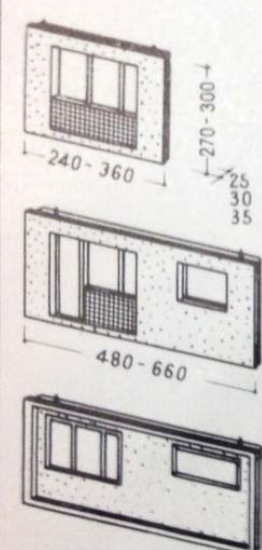
СХЕМЫ ИЗДЕЛИЙ	ТИПО-РАЗМЕР	ГАБАРИТНЫЕ РАЗМЕРЫ СМ	ВАРИАНТЫ АРХИТЕКТУРНО-ПЛАНИРОВ. РЕШЕНИЙ												ДОПОЛНИТЕЛЬНЫЕ ТИПОРАЗМ	ГАБАРИТНЫЕ РАЗМЕРЫ СМ
			I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII		
			T-2A	T-2AЮ	T-2B	T-2BЮ	T-2B	T-2TЮ	T-3A		T-4A	T-4B				
	HC-1	240 × 270														
	HC-2	240 × 260														
	HC-3	270 × 270	•	•	•	•		•	•		•	•				
	HC-4	270 × 260														
	HC-5	300 × 270														
	HC-6	300 × 260									•					
	HC-7	330 × 270														
	HC-8	330 × 260														
	HC-9	360 × 270			•	•		•	•			•				
	HC-10	360 × 260	•	•	•	•		•				•			HC-110	353 × 260
	HC-11	390 × 270														
	HC-12	390 × 260														
	HC-13	420 × 270														
	HC-14	420 × 260														
	HC-15	450 × 270	•	•												
	HC-16	450 × 260														
	HC-17	480 × 270														
	HC-18	480 × 260														
	HC-19	510 × 270			•	•									HC-119	500 × 270
	HC-20	510 × 260							•						HC-120	522 × 260
	HC-21	540 × 270			•	•		•								
	HC-22	540 × 260	•	•												
	HC-23	570 × 270	•	•					•			•			HC-123	560 × 270
	HC-24	570 × 260														
	HC-25	600 × 270														
	HC-26	600 × 260														
	HC-27	600 × 270	•	•	•	•		•				•			HC-127	620 × 270
	HC-28	630 × 280			•	•										
	HC-29	660 × 270									•					
	HC-30	660 × 260									•				HC-130	651 × 260
	HC-31	120 × 270														
	HC-32	120 × 260	•	•					•		•					
	HC-33	690 × 270														
	HC-34	720 × 270			•	•		•				•				

Figure 4.4: Exterior Facade Panel in Construction

<https://vespig.wordpress.com/2014/03/30/%D0%BA%D0%B0%D0%BA-%D1%81%D1%82%D1%80%D0%BE%D0%B8%D0%BB%D0%B8-%D1%85%D1%80%D1%83%D1%89%D1%91%D0%B2%D0%BA%D0%B8/>



Figure 4.5: 9-Story Typical Floor Plan: Volzhsky

Soviet Union, "Arkhitectura SSSR: 1963," no. 1, Page 14

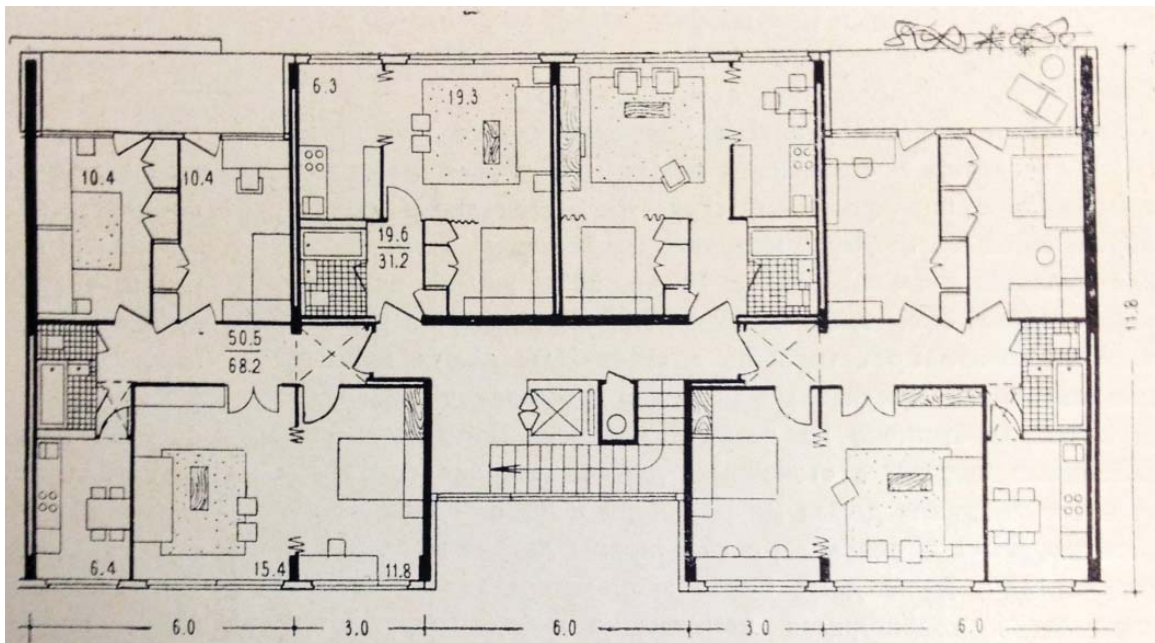
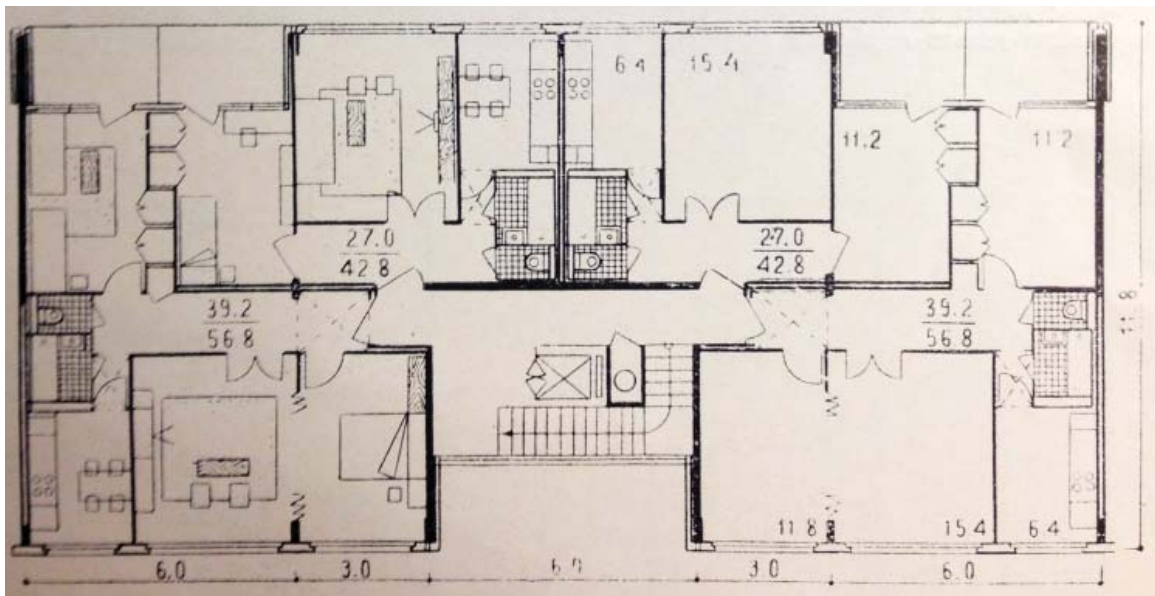


Figure 4.6: 9-Story Typical Floor Plan (Option 2): Volzhsky

Soviet Union, "Arkhitectura SSSR: 1963," no. 1, Page 14



regardless of the interior configuration, which is why the buildings appear so repetitive.

The current Russian building code for this Region would put the R-value requirements for these buildings at 2.8 (IP R-value 15.97) for walls, 4.2 (IP R-value 23.94) for roofs with attics, 3.7 (IP R-value 21.09), for floors above open air spaces or walkways, 2.5 U-value (IP U-value 0.44) for windows and balcony doors and a U-value of 3.33 (IP U-value 0.58) for skylights. The buildings were all mass produced with only minor variations based on materials used until the early 1980's when building codes for energy efficiency began to be upgraded. Consequently, the actual R-values of these walls would be between 0.28 and 0.9 (IP R-value 1.6-5.1), even less for roofs and floors depending on the building, as construction standards were not uniform. Figure 4.9 is a standard building wall section of the three-panel system that was used in Russia for the exterior walls. For comparison, Figure 4.10 is a standard building wall section of these panel systems used in Sweden. An examination of these two figures shows the differences in insulation standards used in these two countries.

Examining the differences between the Russian panel and the Sweden panel; there is a clear difference in the size and thickness of the walls used in Sweden to handle cold temperatures. Furthermore, there is a difference in the materials being used. The Swedish wall panel has a far thicker insulation that is typically a form of EPS foam insulation. However, the Russian panel used a light weight insulating concrete with an R-value between .8 and .9 per inch. In addition, the wall design has more of a continuous insulation, whereas the Russian wall has a break at the floors and wall connection points. When not properly sealed, this can lead to major areas of heat loss. The Swedish walls are almost twice as thick as the Russian walls, and the Swedish connections are lapped over each other which made the sealant more effective and better at minimizing heat loss. Finally, the wall connection points are made with proper drip channels to make water drip off the wall and prevent penetration into the joint.



When water penetrates the joint and freezes, it causes expansion which can damage the sealant and the wall itself. Overall, the construction quality of the three panel wall in Sweden is far superior to the Russian wall which is the main reason why the insulation and energy efficiency of the walls in these Russian buildings is so poor.

The only building element in Russian apartments that, on average, came close to the current building code requirements was the windows which had an R-value close to 0.3 in the Moscow precedent test. However, a significant issue with the windows is that they are leaking air¹² therefore part of the renovation will require re-sealing of the windows to make them a better insulator since the standard window is already close to the minimum code requirements for the latitude, the windows themselves do not need to be replaced. However, to make the buildings more energy efficient, they should be replaced with far better insulating windows. They make up such a significant portion of the building façade that they represent a major heat loss point. Another area to be addressed in the retrofit is the need to check and re-seal the windows that were used to enclose the balconies as most of the buildings had their balconies enclosed sometime after original construction of the buildings.

The typical wall thickness of these buildings is approximately 210 mm (8'2") thick and the typical window is a double pane sliding window that measures 1.5 meters (5') high by 2 meters (6'6") long. Bedrooms and kitchens typically have 1.5 meter by 1.5 meter windows. Each apartment was typically constructed with a balcony that was accessed through a double pane glass door. However, as noted earlier, most of the apartment balconies have been subsequently enclosed and doors may have been removed to open the space and increase the floor area. These spaces are now primarily used for storage for the apartment.

12 Armstrong, Peter, Jim Dirks, Ray Reilly, Bill Currie, Ron Nesse, Oleg Komarov., Boris Nekrasov, "Russian Apartment Building Thermal Response Models for Retrofit Selection and Verification," American Council for Energy Efficient Economy, Page 3.2

Figure 4.9: Standard 3-Panel Wall Section in Russia

Soviet Union, "Arkhitectura SSSR: 1960," no. 2, Page 28

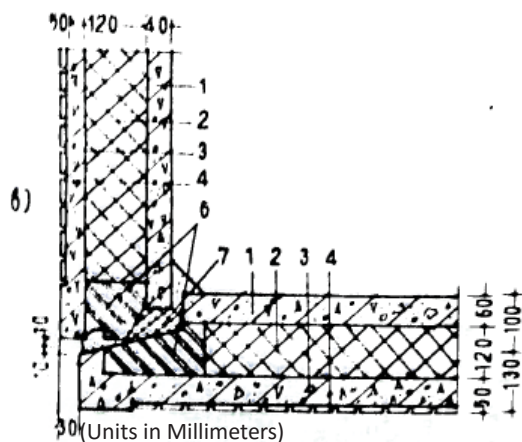
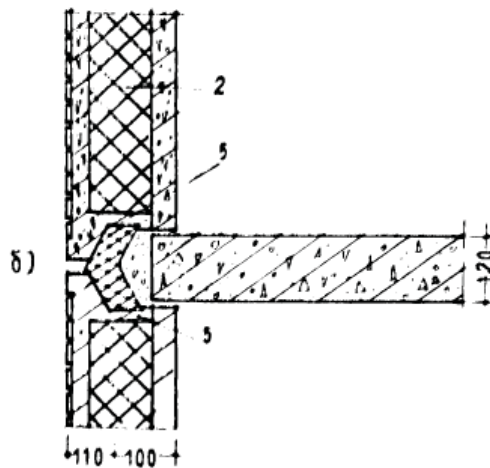
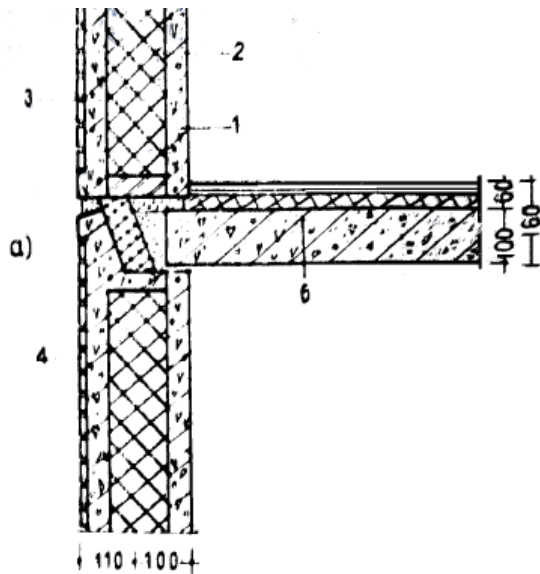
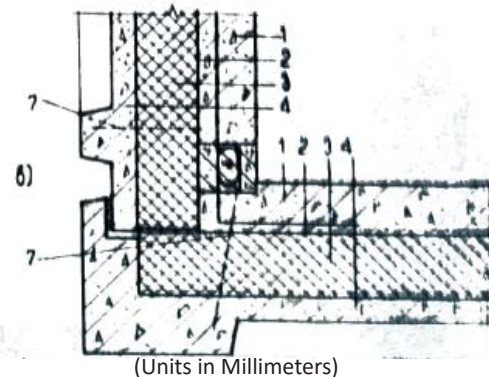
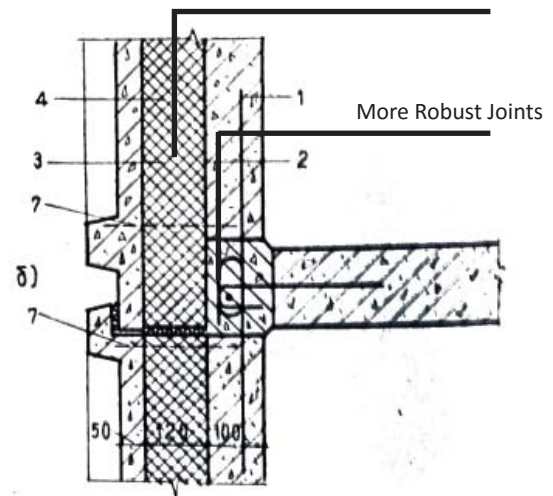
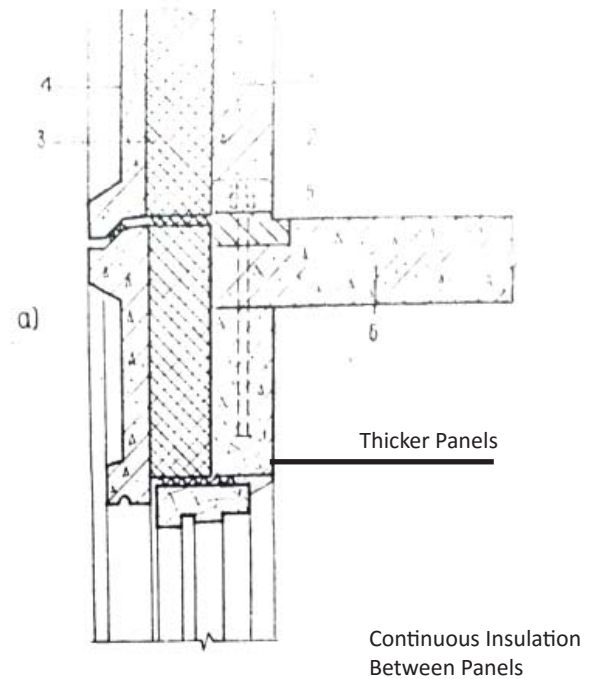


Figure 4.10: Standard 3-Panel Wall Section in Sweden

Soviet Union, "Arkhitectura SSSR: 1960," no. 2, Page 28



The heating, water and waste piping of the building are typically exposed and there is a hot water radiator under each window. This design feature creates additional heat loss. Floor treatment of penetration between floors for the utility systems varied.

¹³ “Doors and windows, passive ventilation channels, smoke control channels, electrical chases, and stair and elevator shafts are the main paths available for air movement into, out of, and through the building.”¹⁴

Specific Site Location

Figure 4.11 is a Map of the 18th Microrayon (apartment block) in Volzhsky which shows the apartment building located at 48 Ultitsa (Street) Druzhby, which has been selected for the site location. This site was selected because it is located in the south western corner of the city which is roughly the middle point between the two combined heat and power plants in Volzhsky. This means that the piping distribution and resulting heat loss are at their greatest and in turn that means this particular section of the city would benefit the most from the improvements to building envelope insulation. The building itself is located in the south eastern section of the housing block. This particular building is incredibly long. With well over 1000 feet in length in one direction, it then turns at a 90 degree angle and continues an additional 600 feet. Due to its size and location, it is an ideal choice for a building retrofit.

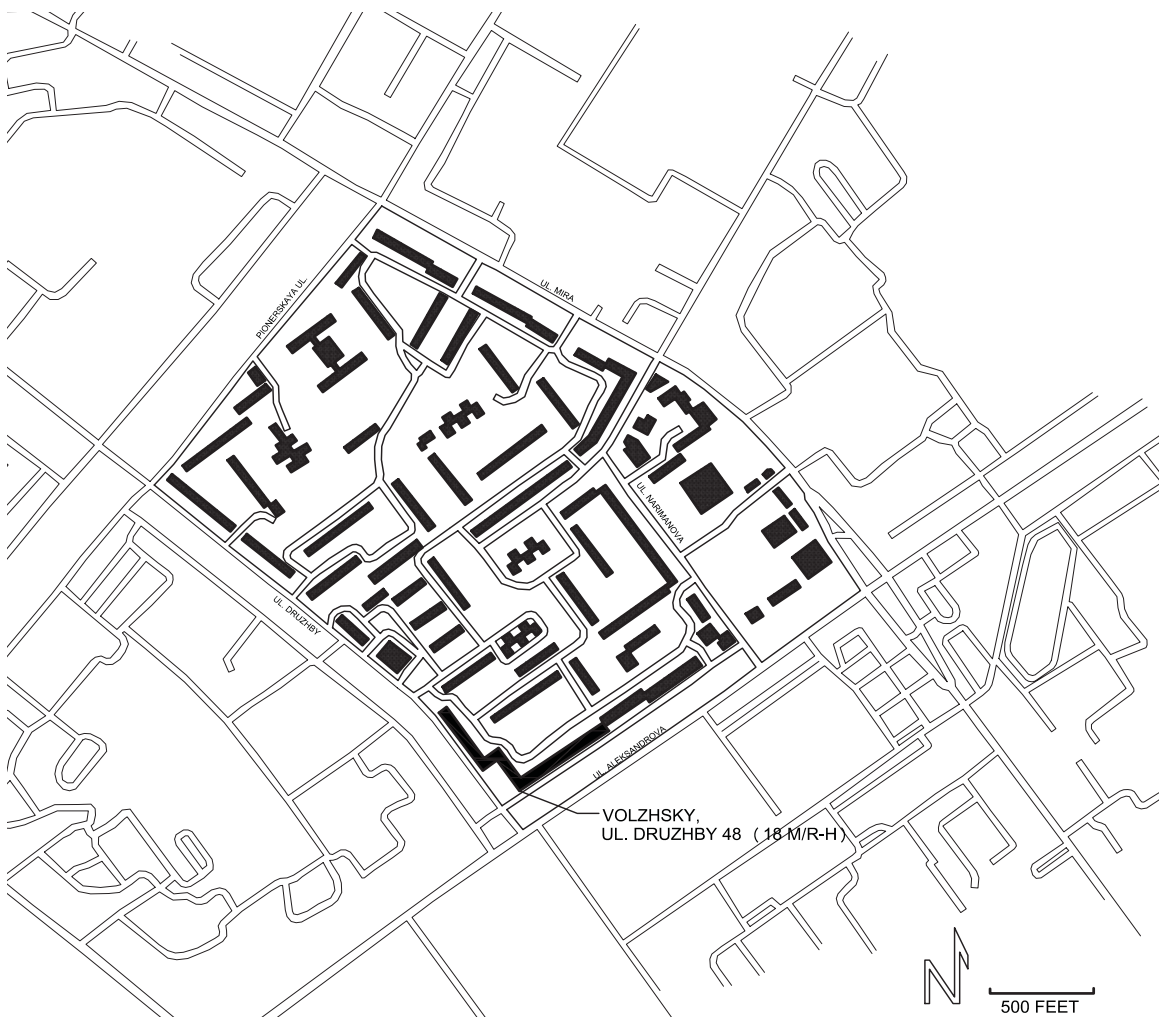
Figure 4.12, 4.13 and Figure 4.14 show the building exterior which is a 9-story standard prefabricated housing structure that was built in the 1960's. While visually, the building appears to be a single structure it actually consists of 13 separate 9-story structures that are built with exterior walls touching each other and sharing a single street address. Each of the 13-9 story structures have 4 units on each floor for a total 468 units. Each of the 13 structures have a separate entry, elevator and central stair

¹³ Armstrong, Peter, Jim Dirks, Ray Reilly, Bill Currie, Ron Nesse, Oleg Komarov, Boris Nekrasov, “Russian Apartment Building Thermal Response,” Page 3.2

¹⁴ Armstrong, Peter, Jim Dirks, Ray Reilly, Bill Currie, Ron Nesse, Oleg Komarov, Boris Nekrasov, “Russian Apartment Building Thermal Response,” Page 3.2

Figure 4.11: 18th Microdistrict Plan in Volzhsky

- Address: Volzhsky, UL, Druzhby 48 (18 M/R-H)
- Construction Typology: Pre-Fabricated Concrete
- No. Floors: 9
- No. 4 Unit Floor Plan Repeats: 13
- Total No. Units: 468
- Total Square Meters: 33,134
- Total Square Feet: 355,650
- Total Exterior Surface Area: ~17,000 Square Meters (182,990 Square Feet)



case that connects the 4 units per floor to a centralized circulation core. Larger units have balconies that have since been enclosed by the residents to use as storage space.

Climate Data

Understanding the specific climatic conditions of the building and the site will help to properly analyze the benefits of added insulation. In addition, I can then compare it to the efficiency improvements that were created by VTT Technical, and as VTT Technical's retrofit was field tested, it provides a base for verification and comparison. Figure 4.15 is a chart with the temperature ranges in Volzhsky in 2014. The temperature varies on a yearly basis from -18 °F to 95 °F, this represents a very large temperature difference throughout the year. When examining the exterior of the buildings in Volzhsky, a large quantity of them have been outfitted with a Russian version of window air conditioner units. The buildings were never designed to have air conditioning, however due to global warming the need for air conditioners has become increasingly important. This was first made evident in 2010 during a heat wave in the summer.¹⁵ After this many of the units had air conditioner units installed. Because of the large temperature range a very efficient building envelope is crucial to creating a more comfortable living environment. In addition, to temperature Figure 4.17 shows the humidity range in Volzhsky and Figure 4.18 shows wind speed.

Figure 4.16 is the psychrometric chart for Kiev, Ukraine, which is at a similar climatic latitude condition as Volzhsky. This chart shows the human comfort level for an occupant in a building in this climate zone or area throughout the year. The green dots represent the lowest and highest temperatures throughout the year and the area marked in royal blue is the comfort zone for a person inside a building in this climate area according to ASHREE Standards 55-2004. The design strategies are detailed in the key in the upper left of Figure 4.16. Some of the passive strategies outlined in the chart

¹⁵ Anastasia Kostetskaya, Personal Interview, May 1, 2015

Figure 4.12: Volzhsky, UL, Druzhby 48 (18 M/R-H)

Google Earth Street View, Volzhsky, UL, Druzhby 48 (18 M/R-H)



Figure 4.13: Volzhsky, UL, Druzhby 48 (18 M/R-H)

Google Earth Street View, Volzhsky, UL, Druzhby 48 (18 M/R-H)

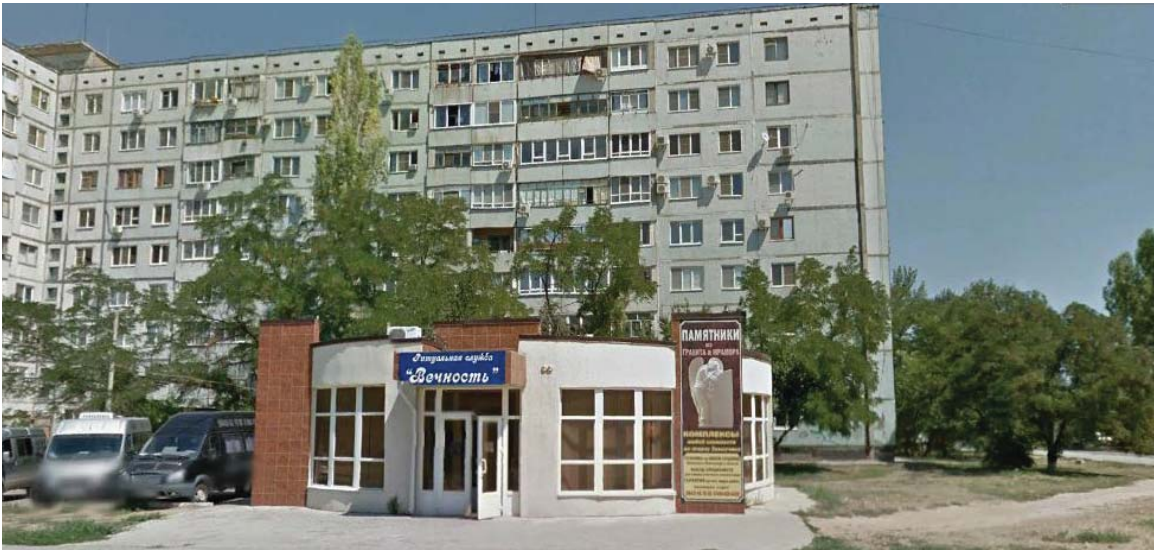


Figure 4.14: Volzhsky, UL, Druzhby 48 (18 M/R-H)

Google Earth Street View, Volzhsky, UL, Druzhby 48 (18 M/R-H)



Figure 4.15: Temperature Range in Volzhsky

Location: Volzhsky, Russia, 49 ° North Latitude, 75 ft above sea level

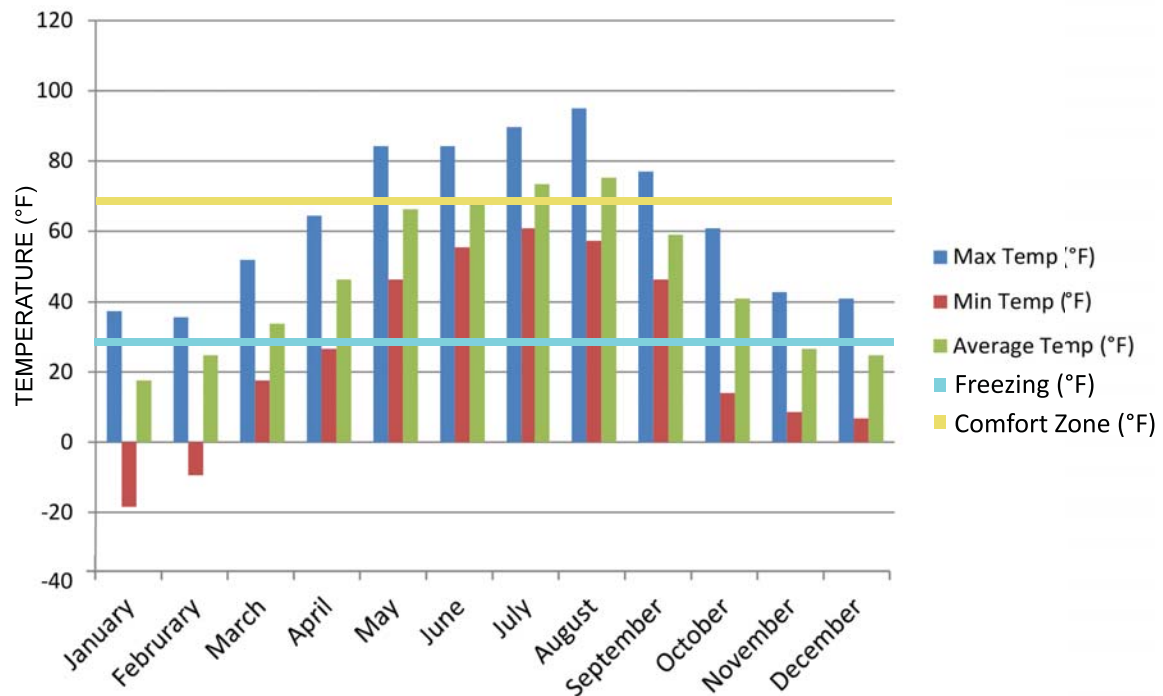
"2014 weather in Volzhskiy Russian Federation." climatevo.com. Visited March, 2015. <http://climatevo.com/2014,volzhskiy,ru>

Figure 4.16: Psychrometric Chart

Location: Kiev, Ukraine 50 ° North Latitude, 587 ft above sea level

"Psychrometric Chart: ASHREE Standard 55-2004 Using PMV," Climate Consultant 6.0, November 18, 2014

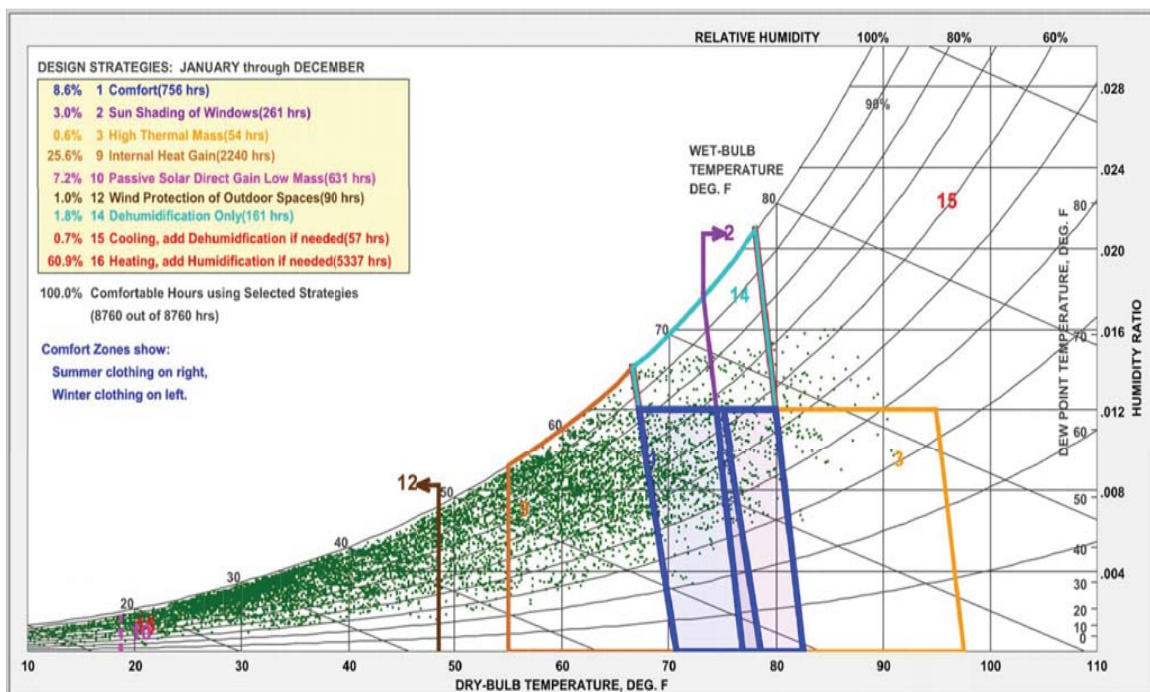
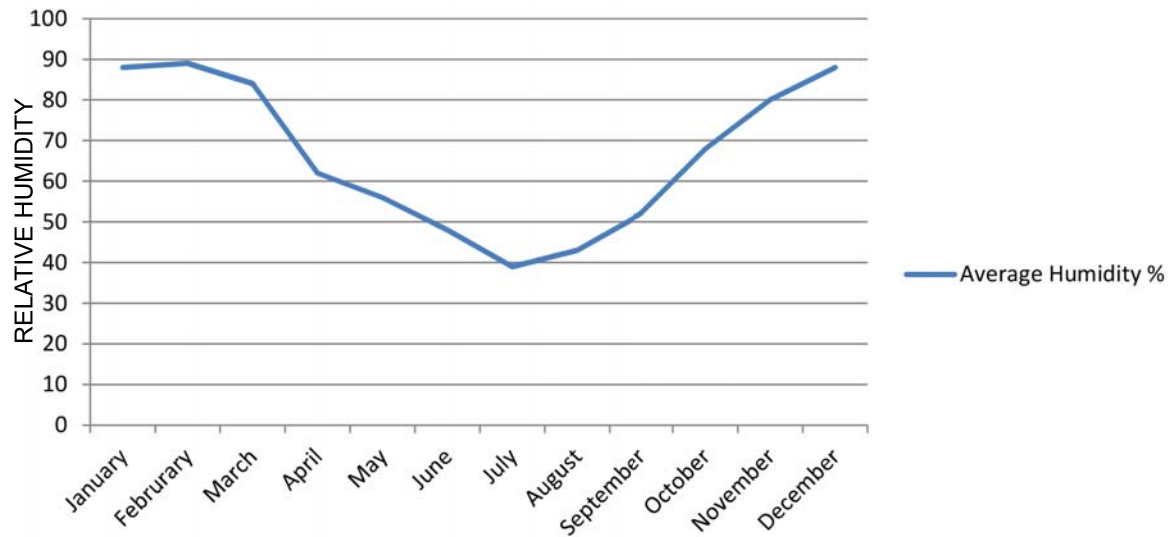
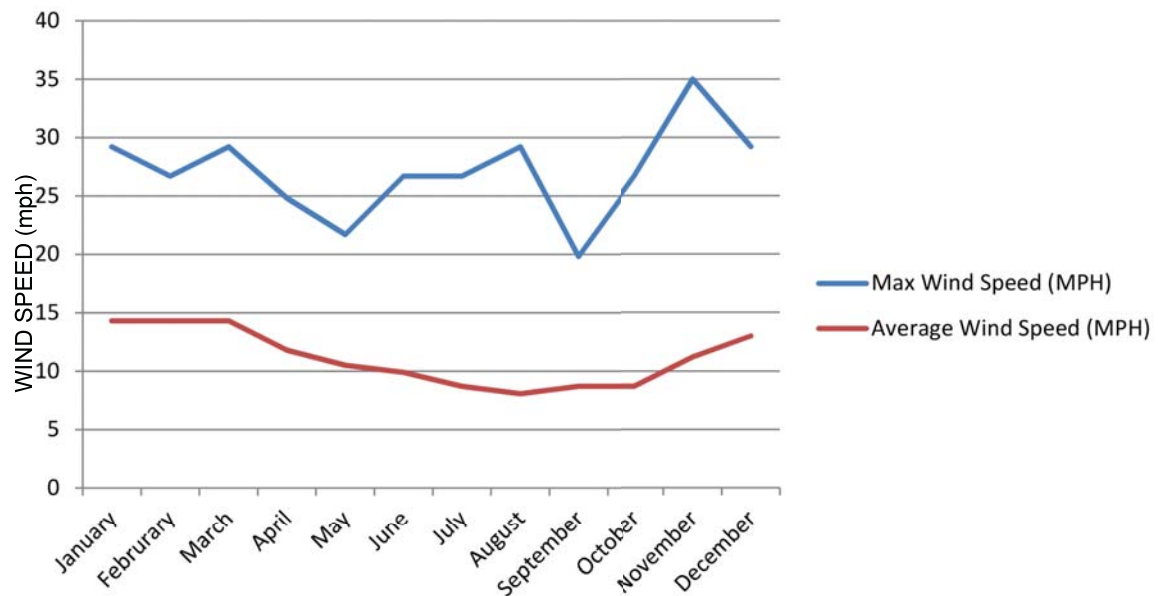


Figure 4.17: Average Month Humidity Volzhsky

Location: Volzhsky, Russia, 49 ° North Latitude, 75 ft above sea level

"2014 weather in Volzhskiy Russian Federation." climatevo.com. Visited March, 2015. <http://climatevo.com/2014,volzhskiy,ru>**Figure 4.18: Wind Speeds in Volzhsky**

Location: Volzhsky, Russia, 49 ° North Latitude, 75 ft above sea level

"2014 weather in Volzhskiy Russian Federation." climatevo.com. Visited March, 2015. <http://climatevo.com/2014,volzhskiy,ru>

would produce a 16.86% reduction of overall energy use in order to keep the occupant in the comfort zone of the space. These strategies are high thermal mass, passive solar gain, wind protection of outdoor spaces, as well as the periodic times of the year that the exterior temperature falls in line with the comfort zone. The remaining 83.14% must be obtained through insulation and interior space heating. This chart shows just how important proper insulation is to minimizing the heat loss of the interior space, in essence lowering the heating energy expenditure to necessary to heat the space.

Financial Conditions of Residents

Part of VTT Technical's retrofit report was a rough cost per square meter for its building retrofit. The product of this research document will improve on the cost and efficiency of the building retrofit options utilized by VTT Technical, thereby, making the overall cost lower. Additionally, it is important to assess the potential cost incentives to the residents in Volzhsky. This can be accomplished by examining the utilities and maintenance expenses currently being paid by the residents of Volzhsky. This in turn will give us a baseline against where to measure the potential added cost to the residents for the retrofit and the potential savings to be realized from the energy efficiency improvement.

When the Soviet Union collapsed in 1991, the residents in these social housing units were given the option to claim the title of their apartments practically free. By the mid-1990's, over one-half of the housing had been privatized.¹⁶ This increased steadily and by 2000 approximately 63 percent of the housing was privatized throughout the county.¹⁷ The privatization efforts are continuing even today as the government is trying to transfer ownership of all the former social housing buildings to the inhabitants. One of the main driving forces behind this desire is that the government is responsible for maintenance on these buildings when they are government owned. However when

¹⁶ Martin McCauley, "Russia: Housing," Encyclopedia Britannica, Updated February 16, 2015

¹⁷ "Urban Slums Report: The Case of Moscow, Russia." Page 19.

Table 4.1: Utility and Housing Expense in Volzhsky

Direct Monthly Housing Expenses	
Building Maintenance	\$11.35
Water	\$2.60
Waste Water/Sewage	\$3.47
Communal Phone (used for exterior entrance security)	\$0.56
Total	\$17.98

Heating and Hot Water Expenses Paid to Lukoil	
Space(District) Heating	\$13.26
Domestic Hot Water	\$5.79
Total	\$19.06

Cooking Gas	\$0.12
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Source: Kira Kostetskaya, Volzhsky, Russia

privatized, some of the maintenance responsibility falls on the unit owners. Some cities such as Moscow are highly privatized with over 74.4 percent of housing being privately owned today as stated earlier.

To get an understanding of the expenses for the private owner in Volzhsky, a local resident was interviewed about her expenses in these old social housing apartments. As of March 2015, the current utility and maintenance expense as quoted from local resident Kira Kostetskaya is shown in Table 4.1. While living in a 5-story building instead of the more common 9-story typology, her building represents very similar utility expenses as the buildings themselves are very similar. She had been living in the apartment since long before the privatization of the building. On average, Ms. Kostetskaya pays the building maintenance cost \$17.98 with only \$11.35 of that amount going to building maintenance and repair. Her average monthly expense for heating and hot water is \$19.06 paid to Lukoil. In addition, she pays \$0.12 for cooking gas. To put these expenses in perspective, the average income after taxes in the Volgograd area is \$495.¹⁸ Expenses and maintenance on the building currently on average is costing approximately 8% of the resident's net income.

Because the numbers are so low, retrofit options are limited to a price that is affordable to the residents. For example, a retrofit cannot create increased costs of \$200 per month to a resident if he or she only averages \$495 per month in net income. These are all important considerations when assessing retrofit options. VTT Technical's retrofit advanced plus option would cost on average 183 euros per square meter or around \$243 per square meter for just the building renovations. The average apartment in the 9-story building is 70 square meters which makes a total cost to retrofit of approximately \$17,000 per unit. It is unknown what the interest rates would be in Russia. However, according to numbeo.com, the interest rate would be approximately 13 percent. A 30

¹⁸ Numbeo.com, "Cost of Living in Volgograd, Russia," Updated January, 2014

year loan with 13 percent interest (the average interest rate in Russia)¹⁹ would cost the average resident an additional \$188 per month.

This is why the cost of the retrofit must be lowered to a more manageable number. When added to the cost of utilities, the net expense per month would be approximately \$227 a month or 46 percent of the total disposable average income of the resident in the Volgograd area. Residents who don't own their own units face an additional expense for rent. The average monthly rent is around \$295²⁰, which is taken together with the utilities would be a total of \$332 per month or 67 percent of the average disposable income for the area. By comparison, in the United States, the average income is \$2630 per month, the average rent is \$752 and the average monthly utility bill is \$158 for a total of \$910 or approximately 34 percent of total disposable income.²¹

This analysis helps to illustrate just how little additional expenses can be taken on by the residents in Russia. However, it is important to note is that most of the individuals in Volzhsky, as well as the rest of the country have little or no mortgage or rent expense because the housing stock was given away after the fall of the Soviet Union in exchange for the Russian government no longer needing to take care of the units that were now privately owned. However, at the same time most of the people living in these social housing buildings live below the average income and poverty line. As of 2001, approximately 52.9 percent of the population in Russia had an income below the cost of living.²² In essence, while they may not have a mortgage or pay rent, they make less money than the average and therefore are limited in total potential debt capability. The importance of finding an affordable retrofit option is even more critical. Because the primary area for improvement in the retrofit lies in a better exterior insulation system

19 Numbeo.com, "Cost of Living in Volgograd, Russia,"

20 Numbeo.com, "Cost of Living in Volgograd, Russia,"

21 Numbeo.com, "Cost of Living in Volgograd, Russia,"

22 Alexander Krashenninokov, "Urban Slums Report: The Case of Moscow, Russia," Moscow Architectural Institute, Page 8

an improvement of 30 percent or more in overall cost would yield a net improvement of around 15% on the total cost of the retrofit. This could lower the cost to the resident by over \$28 dollars per month. While that may not seem like a great deal of savings it could potentially be the difference between making retrofits a possibility throughout the rest of Russia.

Chapter 5: Building Envelope Retrofits: Material Studies

Now that we have a better understanding of the microclimate in Volzhsky, the building specifics, and site specifics as well as previous retrofits that were attempted in Russia, we can begin to examine possible alternative material options. VTT Technical's retrofit used an increasing thickness of mineral wool with a plaster finish coat in each of the different levels of retrofit in the social housing retrofit study they conducted. Each level of retrofit had a progressively thicker layer of mineral wool. However, the overall construction system remained the same.

In order to properly recommend a different approach, we must first have a thorough understanding of the material VTT Technical chose to use for the retrofit and its insulation and installation properties. From there, we can examine different alternatives that will give greater flexibility, easier installation, lower lifetime maintenance costs, lower embodied energy, and larger composition of natural or recycled materials, while still being comparable if not less expensive in construction cost.

Mineral Wool with Plaster Finish

Mineral wool is a form of insulation that is typically made from two different sources of material. One form of mineral wool is made from a substance called "Rock Wool" which is a man-made material composed of natural minerals like basalt and diabase.¹ The other form of mineral wool is called "Slag Wool" which is a man-made material manufactured from blast furnace slag (it is a byproduct of molten steel and typically consists of the impurities that are removed during the refining steel process).² Mineral wool contains roughly 75% post-industrial recycled products or byproducts and

¹ "Insulation Materials," Energy.gov, US Department of Energy, May 30, 2012

² "Insulation Materials," Energy.gov

25% filler and binding materials. It is incredibly fire resistant. Mineral wool is produced in several forms: a roll or batt form (Figure 5.1), a loose fill form (Figure 5.2) and a rigid board form (Figure 5.3). The first two forms are the most common forms of insulation used worldwide.³

Mineral wool is a highly insulative product that has many applications. Due to its availability in a rigid form it can be used on the exterior of a building and not just in the interior of wall cavities like most other insulations. It also has a very high thermal resistance and is able to withstand temperatures of up to 1177°C.⁴ It has an R-Value of approximately 3.7 per inch of insulation. Mineral wool is mold resistant since the material is made of inorganic materials and it has good sound absorption properties.⁵

However, mineral wool is not without its downsides. As a byproduct of the steel manufacturing process or as a form of processed minerals, there are high levels of energy required to create the material; this is called embodied energy. In essence, despite being made from recycled and natural materials, the product requires a substantial amount of energy to produce which means that it is not the most sustainable material. However, overall mineral wool is extremely easy to use and install. Furthermore it is inexpensive.

In the VTT Technical Moscow Retrofit Study, the recommended material was a rigid mineral wool with polystyrene foam for rigidity and a plaster finish coat. Each level of the retrofit was given a thicker level of insulation to increase the R-value and insulative properties of the building. Figure 5.3 is an image that shows the way rigid mineral wool board is installed on a building. After installation a top coat of plaster is added to give a finished and sealed look. Besides the downside of the high embodied energy of this product, the other main issue with the VTT Technical retrofit is the fact

³ "Insulation Materials," Energy.gov

⁴ Insulation Institute, "Mineral Wool Performance: Thermal Performance," NAIMA Canada

⁵ Insulation Institute, "Mineral Wool Performance: Thermal Performance,"

Figure 5.1: Mineral Wool Batt Insulation
http://rigid-wrap1.com/?page_id=238

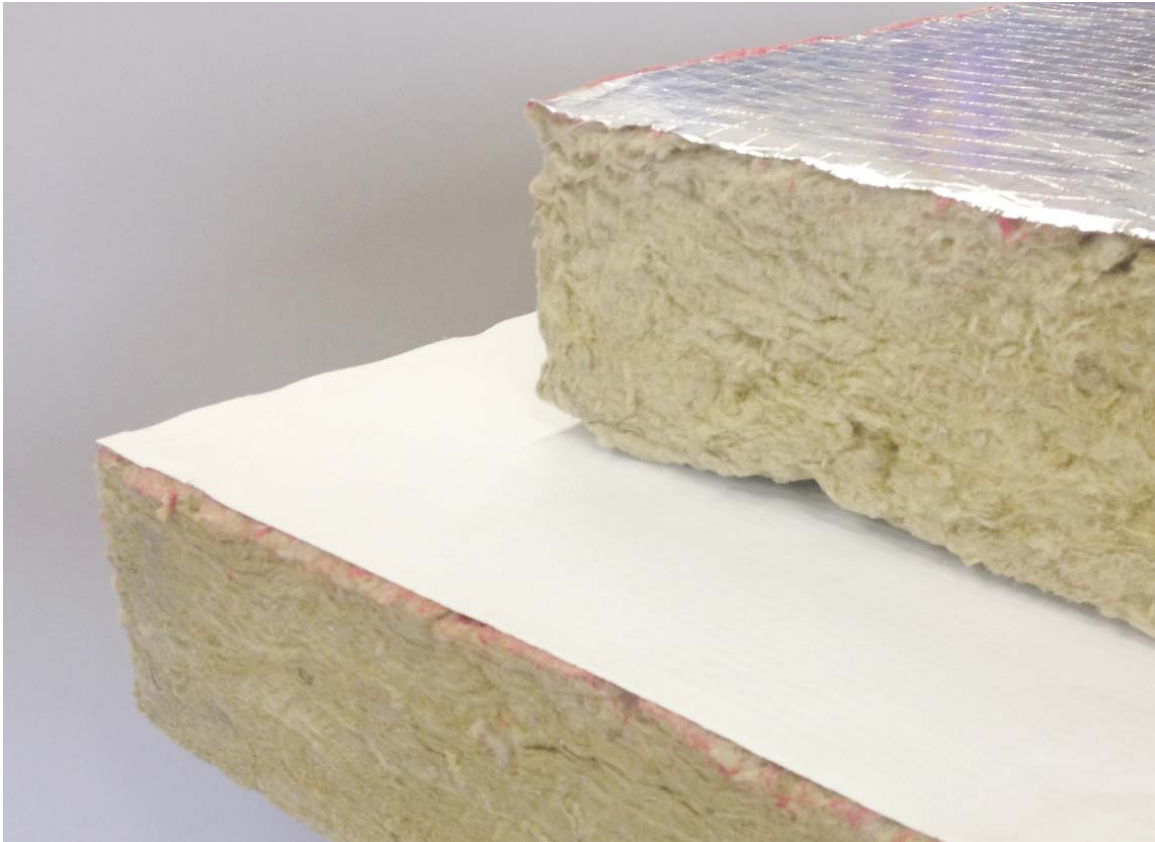


Figure 5.2: Mineral Wool Loose Fill Insulation
<http://becgreen.ca/category/energy-efficiency/insulation/>



Figure 5.3: Mineral Wool Rigid Board Exterior Application

<http://www.greenbuildingadvisor.com/blogs/dept/energy-solutions/mineral-wool-boardstock-insulation-gains-ground>



Figure 5.4: Cracking and Repair of Plaster Finish

<http://www.gciconsultants.com/category/waterproofing/>



that the plastering is somewhat labor intensive which can increase the costs of the retrofit. In addition, there are high maintenance requirements of plaster, including the need to repaint and reseal periodically to minimize cracking. Preventing cracking is incredibly important. If the surface cracks, water can penetrate the plaster and then, as it freezes, it will expand and cause the cracking to become exponentially more extensive. Figure 5.4 is an image of a severely cracked plaster wall. Due to the issues with a plaster coat finish, a better alternative would be a prefabricated insulation panel that can be installed easily and used more efficiently. All in all, an exterior cladding system would be a better alternative.

Material Comparisons

Now that we know what mineral wool is and how it was applied in the VTT Technical building retrofit, we must compare both mineral wool and plaster to alternative materials for both insulation as well as fenestration. This will enable us to evaluate mineral wool with a plaster coat finish in comparison to other materials in the areas of R-value, embodied energy (amount of energy to manufacture and distribute), possible regional manufacturing, lifespan/lifetime maintenance, use of recycled materials and overall cost per square foot. Table 5.1 shows comparisons of different insulation materials and Table 5.2 different building envelope finishes.

After a thorough examination of insulation materials against the different criteria listed in Table 5.1, the most appropriate insulation option is cellulose insulation which typically is made in a loose fill. This criteria for selection are lowest overall price, one of the lowest embodied energy rating, as it is largely made from recycled material. An R-value equal to if not slightly better than that of mineral wool and its only downside to traditional cellulose insulation is that it is made from recycled paper and Russia may not have a system set up to collect recycled paper. Straw bale would be the best option as far as sustainability goes because it has the lowest embodied energy and comes

from the most renewable resource as it is based on a byproduct from the production of grain/wheat which is something that Russia as well as the United States produce in vast quantities.

For the exterior building façade material, VTT Technical recommended a plaster coat finish which had one of the lowest embodied energy rating and longest lifespans. However, it was the most expensive option due to the labor required to install this material. It lacks ease of retrofit because it is difficult to pre-fabricate. Due to the mass production quality of the buildings being retrofitted, a pre-fabricated exterior façade retrofit is the best option to lower the overall cost of each building being retrofitted. A better alternative is a fiber cement exterior siding. This is because it has relatively low embodied energy, one of the lowest costs per square foot, and it is pre-fabricated which saves on installation expense and time to retrofit. Finally fiber cement also has an excellent lifespan at 50 years which is very important because these buildings are already very old and Russia will need the retrofits to last a significant period of time with as minimal maintenance as possible.

It should be noted that the prices listed in the Table 5.1 and Table 5.2 are regional prices from the state of Michigan and they may be different based in other locations. However those prices are comparable to each other as they came from the same location and source and were checked against similar sources for the same location. Therefore, they essentially represent the comparable costs of insulation and envelope materials. VTT Technical used an increased R-value of 10.26 in its basic renovation, an increase of 11.6 in its intermediate option, and an increase of 32.832 for its advanced option. For comparison purposes using the cost reflection Tables 5.1 and 5.2 the VTT Technical mineral wool retrofit would have cost \$4.13 per square foot for the basic renovation, \$4.22 per square foot for the intermediate, and \$5.71 per square foot for the advanced option here in the United States. Using the cellulose insulation with fiber

Table 5.1: Insulation Material Comparison

US Cost for Comparison Purpose (Cost from Michigan)

Material	IP Insulation R-value/ Inch	Total Embodied Energy (MJ/kg/m3)	Material Form	Possible Regional Production	Material Composition	Ease of Retrofit (Time)	Lifetime Maintenance	Recycled Material	Cost per square foot per R value
Mineral Wool 	3.7	386	Batt, Rigid Board, Loose Fill	Yes	basalt or diabase, or blast furnace slag	roughly equal	Minimal (resists mold and moisture)	75% post industrial waste	\$0.06
Cellulosic Insulation 	3.6-3.8	141	Rigid Board, Loose Fill	Yes	paper, mineral borate and ammonium sulfate (for fire safety)	roughly equal	Minimal (resists mold and moisture)	82%-85%	\$0.03
EPS (expanded polystyrene) 	3.8-5	2126	Rigid Board	Maybe	foam	roughly equal	Minimal (resists mold and moisture)	No	\$0.07
Sheep Wool 	3.5	64	Batt, Rigid Board, Loose Fill	Yes	Sheep Wool, Thorlan IW (Titanium Treatment), Latex Rubber, borate	roughly equal	Minimal (resists mold and moisture)	yes	\$0.17
Straw Bale 	1.4-2 (up to 3.04 with pressed board)	91	Bale, Press Board	Yes	straw interior, heavyweight kraft paper on each side	roughly equal	Minimal	No	\$0.07
Cotton 	3.4	60	Batt, Rigid Board, Loose Fill	Yes	cotton and plastic, mineral borate and ammonium sulfate (for fire safety)	roughly equal	minimal borate and ammonium sulfate (for fire safety)	85% recycled cotton, 15% recycled plastic	\$0.04
Polyisocyanurate 	5.6-8	4275	Rigid Board	Maybe	foam	roughly equal	Minimal (resists mold and moisture)	No	\$0.10
Plastic Fiber 	3.8-4.3	low	Batt, Rigid Board	Maybe (need recycling facilities and comparable materials)	Plastic, fire retardant to slow melting	roughly equal	Minimal (resists mold and moisture)	Recycled Milk Bottles	x
Fiberglass Batt 	3.7	336	Batt, Rigid Board, Loose Fill	Yes	Glass fibers	roughly equal	Minimal (resists mold and moisture)	20%-30% recycled glass	\$0.03

Table 5.1 Sources:

"House of Straw-Straw Bale Construction Comes of Age." Balewatch.com. April 1995. <http://www.balewatch.com/technique.html>
 Jones, Craig. Geoff Hammond. "Inventory of Carbon & Energy: V2.0" Sustainable Energy Research Team. Department of Mechanical Engineering. University of Bath, UK. 2011.

Eco Calculator.com. "Intallation Application and Cost." Vested March 7, 2015. <http://www.ecoevaluator.com/building/energy-efficiency/insulation-application-and-cost.html>

"Embodied Energy of Building Materials." CanvonDesign. 2013. <http://media.cannondesign.com/uploads/files/MaterialLife-9-6.pdf>

Sheep Wool Insulation. "Common Questions: What is embodied energy?" Visited March 7, 2015. <http://www.sheepwoolinsulation.ie/support/faq.asp>

Table 5.2:Envelope Material Comparison

US Cost for Comparison Purpose (Cost from Michigan)








Material	IP Insulation R-value/ Inch	Total Embodied Energy/ (MJ/kg/m3)	Possible Regional Production	Material Composition	Ease of Retrofit (Time)	Lifespan and Lifetime Maintenance	Recycled Material	Cost per square foot
Stucco/Plaster Coat 	0.2	1440	Yes	Plaster with typically a wire mesh or resin mesh	24 Hours per coat (Typically 3 Coats Plus Paint)	50+ Years: Periodic Repainting and Filling of Cracks Required	No	\$3.41
Metal Panels/Cladding 	0.61	188,000	Yes	Steel with 20% Nickle	Very Fast Pre-Fab, Quick install	20-50 Years: Minimal to none	Yes	\$2.60
Vinyl or Platic Panels/Cladding 	0.61	106,536	Yes	Vinyl Plastic	Very Fast Pre-Fab, Quick install	25 Years: Minimal to none	No	\$1.71
Recycled Plastic Cladding 	0.61	99,498	Maybe	Recycled Vinyl Plastic	Very Fast Pre-Fab, Quick install	25 Years: Minimal to none	Yes	\$1.71
Wood Cladding 	0.8	4608	Yes	Wood	Fast, Pre-Fab, but requires painting and sealing	25+ years: Moderate to High, Requires Frequent Repainting	No	\$3.58
Fiber Cement 	1	5300	Yes	Cement with sand and cellulose fibers	Fast, Pre-Fab, but requires cocking	50 Years: Low	No	\$2.15
Hardboard 	0.8	9600	Yes	Wood particles pressed together	Fast, Pre-Fab, but requires painting and sealing	10-25 Years: Moderate to High, Requires Frequent Repainting	Yes	\$1.91

Table 5.1 Sources Continued:

US Department of Energy. "Types if Insulation." Energy.gov. Visited February 6, 2015. <http://energy.gov/energysaver/articles/types-insulation>

Wilson, Alex. "Energy Solutions: Mineral Wool Insulation Entering the Mainstream." Building Gree.com. November 2013. <http://www2.buildinggreen.com/blogs/mineral-wool-insulation-entering-mainstream>

Table 5.2 Sources:

"R-values for timber framed building elements - walls." FWPRDC: R-values for Timber Framed Building Elements (Edition 2.1). <http://www.tastimber.tas.gov.au/species/pdfs/Rvalue1-Edition-2-Walls.pdf>

"Components: Cladding (siding)." Minnesota Green Affordable Housing Guide. 2007. http://www.greenhousing.umn.edu/comp_cladding.html

"R-Value." Sizes.com. September 2003. <http://sizes.com/units/rvalue.htm>

"R-Value Table." Residential Shipping Container Primer. Visited March 7, 2015. <http://www.residentialshippingcontainerprimer.com/R%20Value%20Table>

Jones, Craig. Geoff Hammond. "Inventory of Carbon & Energy: V2.0" Sustainable Energy Research Team. Department of Mechanical Engineeering. University of Bath, UK. 2011.

Table 5.3: Cost Comparison Chart

		Material Cost Comparison			Total Renovation Cost Comparison		
		Basic Option	Intermediate Option	Advanced Option	Basic Option	Intermediate Option	Advanced Option
VTT Technical (Mineral Wool, Plaster Coat Finish)	Cost Per Ft ²	\$4.13	\$4.22	\$5.71	10.40 € (\$13.83)	13.14 € (\$17.49)	17.09 € (\$22.73)
	Cost Per M ²	\$0.38	\$0.39	\$0.53	111.92 € (\$148.85)	141.48 € (\$187.63)	183.86 € (\$243.46)
Proposed Design Alternate (Fiber Cement, Cellulose Insulation)	Cost Per Ft ²	\$2.41	\$2.45	\$3.08	8.79 € (\$11.69)	11.12 € (\$14.78)	14.12 € (\$18.78)
	Cost Per M ²	\$0.22	\$0.23	\$0.29	94.56 € (\$125.76)	119.61 € (\$159.08)	151.95 € (\$202.09)
Total Difference Percentage		41%	42%	46%	15.60%	15.40%	17.40%

cement cladding would have cost \$2.41 per square foot (41% less) for the basic option, \$2.45 (42% less) for the intermediate, and \$3.08 (46% less) for the advanced option. That is a significant level of savings that can be realized simply by using a different form of insulation and exterior finish material for the retrofit.

This is summarized in Table 5.3 showing the cost comparison of a superior material selection to that of each option proposed by VTT Technical. For the purposes of this comparison only the effect on the new exterior insulation is reflected in the total renovation cost comparison, all other cost of the renovation are unchanged (i.e. the replacement of the windows, ventilation, heating, water and waste water, electricity, gas and metering.)

Alternative Insulation Systems

Now that we have evaluated different materials in comparison with the retrofit option offered by VTT Technical, we must now investigate the most appropriate system to attach the new insulation and siding material to the concrete façade of the social housing buildings in Volzhsky. Cladding systems are one of the best forms of exterior siding that can be used in a building retrofit. Since the preferred exterior finish of the material based on the evaluation is fiber cement siding, this implies the use of a

prefabricated panel which works best as a cladding system. There are three major forms of attachment that can be used in an exterior insulation cladding system. The first is an exterior cladding panel fixed to a sub-grid system on top of insulation board. The second form is an exterior cladding fixed to a sub-grid attached directly to the building façade with insulation placed between the attachments to the façade. Finally, the third form is a pre-fabricated insulated panel that is attached to a sub-grid system fixed to the façade.

Exterior Cladding Panel Finish over Insulation

One of the major issues with the insulation system recommended by VTT Technical was the plaster coat finish. This material would require more maintenance over the years. In order to explore the best exterior finish, a thorough examination of different insulation systems must be conducted for comparison. One alternative to this system would be an exterior cladding system that operates mainly as a rain screen or finish over the top of the insulation itself. This would allow for faster installation and easier maintenance over time. There are a few different types of insulation material applications that operate within this system of insulation with cladding panels on top. This application would still use mineral wool as the main method of insulation improvement on the exterior of the building. However it would have a different finish. One such exterior finish product is called IntelliScreen.

IntelliScreen is a pre-fabricated exterior insulation attachment system that has a mineral wool board bolted to the exterior of the building. Their particular mineral wool is a “high-density rigid insulation board, designed specifically for evolution, repels water, is non-combustible, provides outstanding thermal insulation, and does not propagate the growth of mold or mildew.”⁶ The rain screen is attached to the insulation board: with a “perforated sub-girt (patent-pending) for panel attachment creates the crucial one-inch air cavity for ventilation, and virtually eliminates thermal bridging.”⁷ Finally

⁶ IMETCO, “InelliScreen: Complete Rainscreen Wall Systems,” Innovative Metals Company

⁷ IMETCO, “InelliScreen: Complete Rainscreen Wall Systems”

there is a metal wall panel finish that is attached to the sub-grid. These metal panels come in a variety of materials, colors and finishes. The R-Value of this insulation system is based on the mineral wool being used and as such has approximately a 3.7 R-value per inch. A diagram of the IntelliScreen exterior façade system is shown in Figure 5.5 and 5.6.

Exterior Cladding with Insulation within Grid System

The next form of exterior insulation attachment system utilizes a mineral wool or equivalent insulation that is placed within an attaching grid system with a metal rain screen panel covering the insulation. This form of insulation attaches the prefabricated metal panel grid directly to the façade for increased stability. The insulation is then placed in-between the wall and the frame and the cladding panels cover the entire system with any finish or cladding style desired. One of the advantages of this insulation attachment system is that the insulation is attached using on a grid layout, so that if the insulation is damaged for any reason, it can be easily replaced.

One product with this form of cladding system is manufactured by Allface. Their system is called the Smart Fixing System. It bolts directly to the façade and insulation is attached to the frame with a cladding system placed on the top. R-values remain the same since they use mineral wool. A diagram demonstrating the Allface exterior façade system is shown in Figure 5.7.

Exterior Insulated Cladding Wall Panel

The final form of exterior insulation cladding is a combined system which consists of cladding with insulation on its interior. This is a single-panel system that is fastened to the façade and all the insulation properties are present in the cladding itself. Because the entire system is self-contained, installation is very fast and relatively low cost. Each manufacturer will use a different form of interior insulation to achieve its R-values,

Figure 5.5: IntelliScreen Structural Break Down
http://imetco.com/media/IntelliScreen_Rainscreen_Brochure.pdf

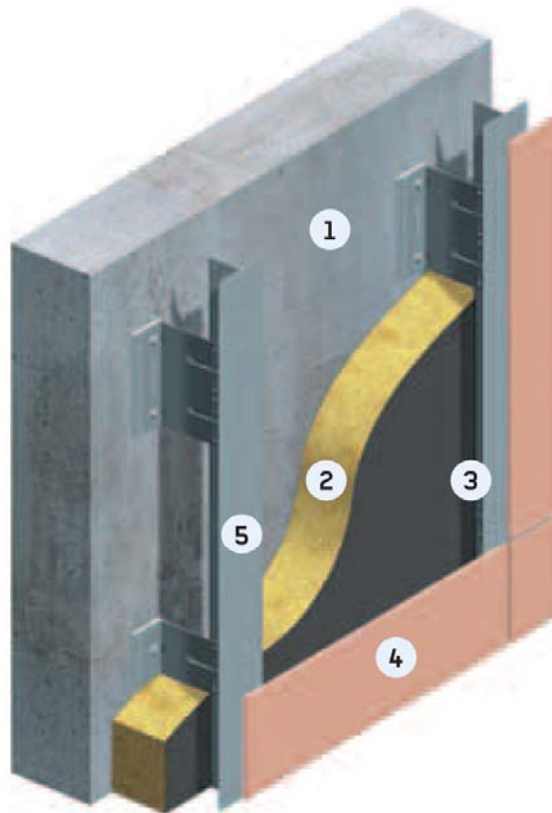


Figure 5.6: Intelliscreen Finished Façade Example
http://imetco.com/media/IntelliScreen_Rainscreen_Brochure.pdf



Figure 5.7: Allface Exterior Insulation Cladding
<http://al007rz5.edis.at/wp-content/uploads/2012/04/Allface-Technic-Brochure-EN.pdf>

SYSTEM F1.10



CONSTRUCTION OF THE RVF

- 1 Load bearing wall
- 2 Insulation
- 3 Ventilation space
- 4 Facade panel
- 5 Allface substructure

however, the insulation typically used is a form of EPS foam or mineral wool.

An example of this product is produced by Kingspan in the United States. They make both an exterior cladding with insulation within the grid as well as an insulated cladding wall panel. They use a form of foam insulation for both systems and their total R-value is higher than that of mineral wool meaning that the façade does not need to be as thick in order to achieve the same level of insulation.⁸

Kingspan's insulated metal wall panel has an R-value of 7.5 per inch which is about double the R-value of mineral wool. "Most importantly, the insulation is on the exterior of the building structure to provide the best possible thermal envelope by reducing thermal bridging typical of cavity wall systems. In addition, the panels feature excellent foam-to-foam contact, which provides an unbroken thermal shield against heat transfer."⁹ The panels come in a variety of different finishes and colors. There are also different attachment mechanisms depending on the desired aesthetic look. The panels can be on a standard cladding grid similar to the products mentioned earlier, but also have the option to have concealed overlapping connections which make the surface look like one large material surface. These options are available for the metal panels with more of a corrugated fenestration.¹⁰ Because of the unified system of installation, Kingspan claims their product can be installed 50% faster than other forms of built-up cladding insulation systems. In Figures 5.8 and 5.9 the structure of the Kingspan panel is shown along with the attachment system.

Conclusion of Building Material Studies

VTT Technical's retrofit study represents a solid step forward in a solution for a more thermally insulating building façade for the mass-produced social housing buildings in Russia. However, its recommendation of mineral wool with a plaster coat

⁸ Kingspan Insulated Metal Products, "Insulated Wall and Roof Panels," IRW Broucher

⁹ Kingspan Insulated Metal Products, "Insulated Wall and Roof Panels,"

¹⁰ Kingspan Insulated Metal Products, "Insulated Wall and Roof Panels,"

Figure 5.8: Kingspan Insulated Wall Panel Construction

<http://www.kingspanpanels.us/kingspanunitedstatesmain/media/pdfDownloads/Insulated%20Roof%20and%20Wall%20Panels/Insulated%20Metal%20Wall%20Panels/Literature/Insulated-Roof-Wall-Brochure.pdf>

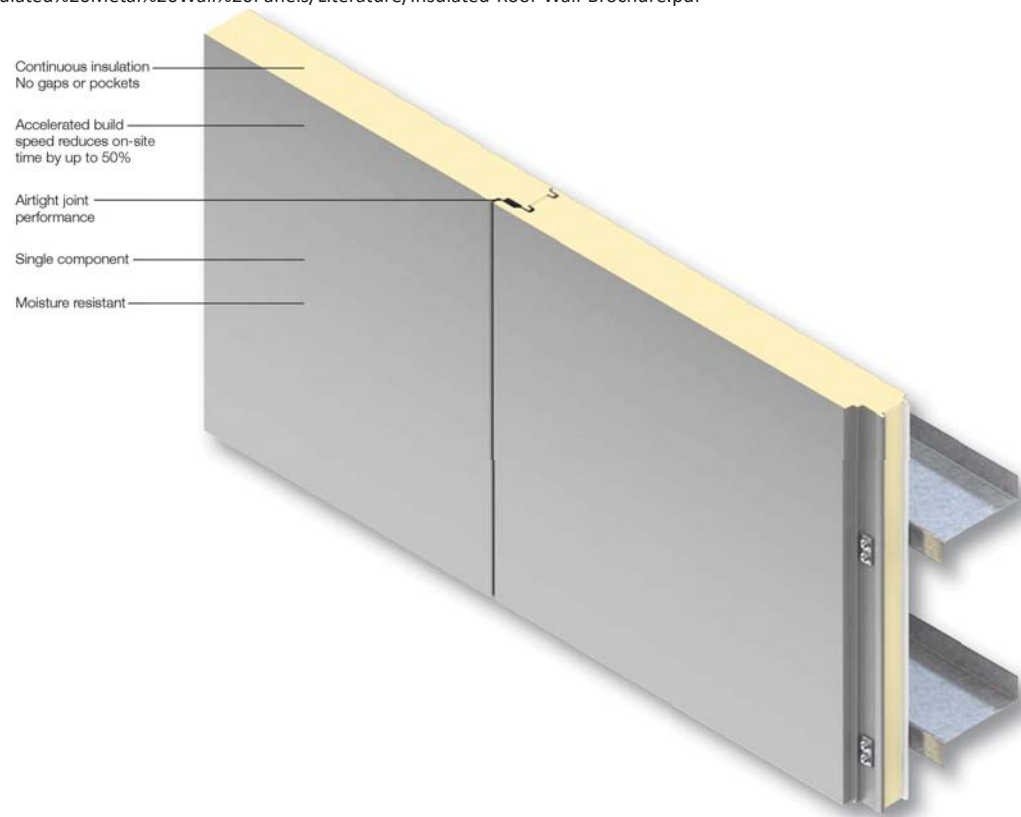


Figure 5.9: Kingspan Insulated Wall Panel Grid Construction

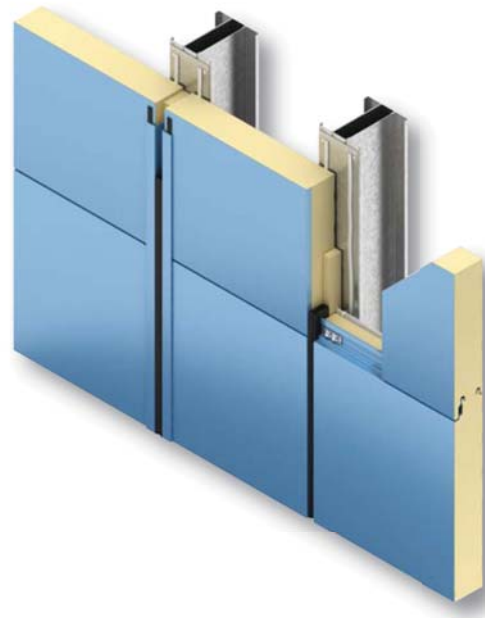
<http://www.kingspanpanels.us/kingspanunitedstatesmain/media/pdfDownloads/Insulated%20Roof%20and%20Wall%20Panels/Insulated%20Metal%20Wall%20Panels/Literature/Insulated-Roof-Wall-Brochure.pdf>

Design Flexibility and Aesthetic Appeal

Kingspan's commercial and industrial wall and roof systems offer designers a comprehensive range of building solutions for vertical and horizontal wall applications.

Available in multiple profiles, finishes and color options, trimless ends and cover widths, insulated panels provide customized building design and creative freedom.

The panels are easily integrated with traditional construction methods and building systems.



finish is not the best approach for improvement of the façade. The labor expense of installation as well as the life time maintenance expense associated with a plaster coat is not the best option. In addition to this, mineral wool is not the best insulating material due to its higher embodied energy and cost. Cellulose insulation with a fiber cement panel exterior façade system would represent a much more sustainable and affordable option for the retrofit system, saving over 40% on average for each level of retrofit.

After examining different exterior insulation façade systems, the best option is an exterior insulation cladding wall panel system using a pre-fabricated insulated panel. This system is the fastest system to install as it is capable of being installed 50 percent faster than the other built-up layered systems. The exterior cladding should be comprised of a fiber cement shell with a cellulose insulation on the interior. This form of prefabricated panel is not manufactured currently. Virtually all the prefabricated insulated wall panels are made with a form of EPS or other rigid foam equivalent for the insulation due to its light weight and strength and moisture tolerance. There are fiber cement rain screens currently being made, but these systems fall under either the insulation within grid system or grid on top of insulation system, or they have an EPS Foam core for increased structural stability. An exterior insulation cladding wall panel system using a pre-fabricated fiber cement panel and cellulose insulation would be far less expensive and more sustainable building material as opposed to the current retrofit option presented by VTT Technical and would represent the best option for the retrofitting of these old prefabricated social housing apartment buildings.

Chapter 6: Summary of Findings

Intent of Literature Exploration

Russia's current housing situation has deteriorated to an unacceptable condition. The buildings were originally constructed with a main driving force of cost minimization and consequently, were not built to a high construction standard. In addition, they have received minimal if any maintenance over the years making them degrade at an increased speed. The goal of this literature exploration was to determine how heating systems and energy efficiencies could be improved; specifically to examine possible upgrades to the district heating system upgrades or the build envelope efficiency upgrades. Finding the most efficient solution will provide a potential retrofit option for Russia and its inhabitants to consider. This has the potential to significantly improve the lives of millions of people currently living in a very old outdated social housing. Since the majority of the social housing supply is currently privately owned, current owners also need to have potential options for making upgrades to the building envelope in the most cost effective and sustainable manner.

Summary of Existing Body of Knowledge

Russia has seen a very dynamic history of housing development over the past 80 years. They have gone from having a massive need for housing to a mass production of "temporary housing" that has existed long beyond its intended lifespan of 25 years. These houses were created at a time when no energy efficiency building standards existed in the country, and consequently, they have incredibly poor thermal insulation and energy efficiency. When a building is not properly insulated, two major problems can occur. The building can require enormous amounts of energy and cost to heat,

and it may not be possible for the building's interior temperature to be brought to acceptable human comfort standards despite high amounts of heating energy used in the building.

Currently Russia's district heating system is extremely outdated, requiring replacement of: 70% of the overall system; 80 percent of the boilers; and over half of the 180,000 miles of district heating piping. With such a massive percentage of the system needing to be replaced, interruptions in service are frequent and the overall cost to run the system is enormous due to the massive efficiency losses that occur in both the production and the distribution of heat. Russia stands to gain approximately 8-9 billion dollars annually in energy savings if the district heating system is updated and replaced. However, as noted earlier, updating the district heating system will not eliminate the massive heat losses that are occurring at the building level. In essence, the system could be running perfectly, but it would still be wasting enormous amounts of energy and potentially is unable to heat the interiors of the buildings to acceptable levels. Currently, the greater need in Russia is to update the buildings throughout the country with more efficient building insulation systems.

With a more energy efficient building, the interior demand on the heating system can be lowered drastically, thereby allowing for an acceptable interior comfort level with much less energy. The overall cost to replace the district heating system is so massive that the government is looking to private financing to help with the expense. Part of the difficulty with updating the district heating system is that in order to be effective, you must replace significant enough portions of the system in order to see improvements in the efficiency of the system. Periodically replacing a piece of piping or a single boiler will do nothing in the long run for improving the efficiency of the system. However, building efficiency retrofits can be done at a pace that is affordable to the Russian government. In addition, as many of the apartment buildings are now privately owned,

the government could offer more of a subsidy or incentive to the owners to upgrade their buildings.

Improving the energy efficiency of the buildings will make them more livable. Additionally, once the district heating system can be financed and improvements are completed, there will be efficiency improvements in heat generation and distribution, as well as, reductions in cost at the individual building level. The concern about the energy efficiencies of the old social housing buildings in Russia is not a new problem or notion. The need for improved energy efficiencies has been apparent to Russia since 1979 when the country began energy reforms. However, as these energy reforms were not reflected in the building codes until after 1995, the social housing buildings in the country were built without the benefit of energy efficiency standards.

Russia has since investigated many different possible approaches to improvement of the efficiencies of these buildings. These investigations began as feasibility studies in 1996, after the first round of new energy codes were released in Russia. These initial studies investigated the feasibility of updating the exterior insulation and building envelope efficiencies of the old social housing apartments. The studies tested existing U-values of the exterior walls and performed data analysis of other potential energy savings areas such as air leakage. The purpose of these studies was to see if there was sufficient room for improvement to warrant conducting full scale renovation studies in Moscow, the city chosen for the upgrade test study.

The next phase of investigation was the full scale renovation of a selected building block. This was compared with options for replacing these buildings. At the same time, Moscow's district heating system was receiving a major overhaul, replacing all 5,932 miles of piping in Moscow with a new stronger, more flexible pre-insulated polymer piping system. After these initial tests, Russia determined that replacement was preferable. This was not because it was more cost effective to construct the new

buildings than it was to retrofit the old units. Rather it was because of a political mindset in Moscow, that the old social housing apartments were originally represented to the people to be a temporary housing solution and the government wanted to make good on that promise by replacing those apartments with newer and nicer apartments.

Replacing the social housing apartments proved to be too expensive in the long run and after a minor financial crisis in Russia in 2008, replacement slowed and new options of retrofit were investigated. The Russian government determined that they would finish the upgrades in Moscow, but replacing the housing units across the country would be far too costly. Another issue that arose during the Moscow retrofit was that the units were replaced by private contractors. Because these contractors wanted to make a profit in the process of building the new apartments, the current residents would typically be unable to afford the new units. A new unit costs on average \$2600 per square meter in 2012 to construct. This is a cost that is far too expensive for the typical Russian resident to afford.

Retrofit by VTT Technical

As replacement has proven to be too costly, new retrofit studies were conducted in Moscow with some of the remaining units that had not been replaced. VTT Technical conducted a very thorough retrofit study on several buildings in the district of Zelenograd, Moscow. In their retrofit study, VTT Technical conducted evaluations on improvements to the building envelope, district heating upgrades, replacement of district heating system with solar heating and a thermal heat pump, as well as financial evaluations of the renovations, with a complete cost analysis. Overall their study was very thorough. However it has a few areas that can be improved upon. These areas of improvement were revealed after examining potential alternative material, insulation and assembly systems for the building exterior retrofit.

The largest area of concern was price when looking at the retrofit by VTT Technical. While their system was very efficient and accomplished the goals of the retrofit, the typical price for the retrofit was approximately \$17,000 per 70 square meter unit. Financing this cost would result in a monthly expense of approximately \$188. This is not an extremely high expense in Moscow. However as the majority of the residents of cities outside Moscow have a much lower disposable income, this price becomes far less feasible. In the Volgograd area, the average income was less than \$495 a month which would make financing a renovation like the one recommended by VTT Technical incredibly difficult and as Volzhsky represents more of the typical norm for the country, a retrofit option must be generated that can accommodate their typical income bracket.

In addition to examining financial considerations of the VTT Technical retrofit, I developed a design concept for a better, more adaptable, less expensive, easier to install, more sustainable, lower lifetime maintenance exterior insulation system. Creating a more adaptable prefabricated system also opens up the possibility for financial savings. After examining many different potential materials for both insulation and fenestration, it has been determined that cellulose insulation with a prefabricated fiber cement panel would be the most cost effective (about 40% less expensive than VTT Technical's system of mineral wool with a plaster coat finish), sustainable option with an incredibly low lifetime maintenance requirements. In addition, the system could be manufactured in a manner that would be very easy to install when created as a single prefabricated panel with the insulation built into the material.

Site Conditions

Before a design solution can be created, a thorough examination of the site conditions was necessary. This involved an examination of more macro conditions such as information about the city of Volzhsky, its building history as well as its current district

heating system. In addition, more micro site conditions such as the weather conditions, specific site location and its relationship to the surroundings were investigated. The main housing typology in Volzhsky is the 9-story prefabricated typology, due to the age of the city with constructing of social housing commencing in large part after the early 1960's.

A key site condition to consider is that even though Volzhsky is much further south than Moscow, the temperature in Volzhsky can get quite cold, reaching below -18 degrees Fahrenheit. The design solution must protect against not only the extreme cold but also against the heat as the temperature in Volzhsky can also get in the mid 90's in the summer. This is a temperature swing of over 115 degrees between Volzhsky's coldest day and it's warmest. In addition, Volzhsky is so far south that it has a much lower code requirement for building envelope efficiency, consequently the new insulation value should be rated higher than the code standard due to the climatic fluctuations of the area.

Conclusion of Literature Review

The problem of poor energy efficiency in housing in Russia is not an unexplored area. To the contrary, there have been many different feasibility studies and investigations that have examined improvements to both the district heating system and the building envelope efficiency of the millions of old prefabricated social housing apartments. However, the greatest obstacle to making these improvements is that the more affordable options are needed because the improvements will largely be financed by local residents renovate their own apartment units.

The financial limitations of the previous retrofit options are only one area that could be improved upon. My design is going to improve not only the financial expense for the residents, but it will provide of a better, more adaptable, less expensive, easier

to install, more sustainable, lower lifetime maintenance exterior insulation system. In addition, the design will utilize a prefabricated insulated panel which will create a far more aesthetically appealing building envelope design than any of the previous retrofit designs in the past. Figure 6.1 is a timeline of the social housing development in Russia from the Russian Revolution until VTT Technical's retrofit study. Included in the timeline are the years of housing development as well as the new code implementation and case studies conducted in Moscow. The next step in the evolution for Russian energy efficiency improvements in their housing sector will be a better exterior insulation system that I have designed.

Figure 6.1: Timeline of Housing Development

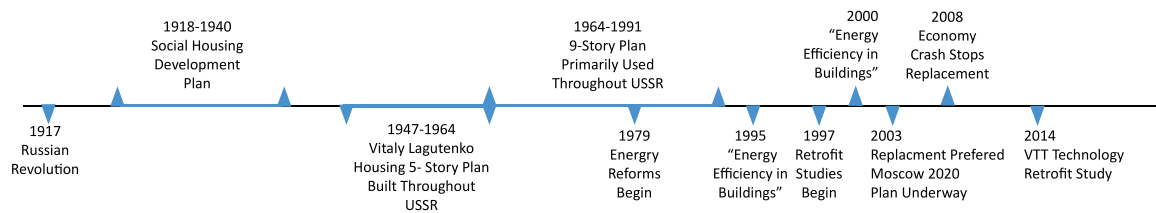
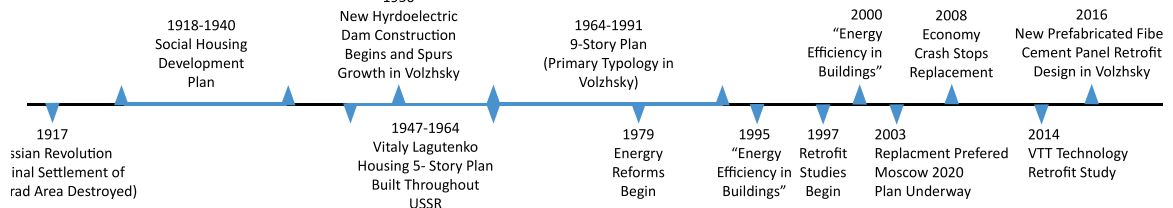


Figure 6.2: Timeline of Housing Development



Design/Research Documentation

Chapter 7: Building Retrofit Design Development

During the design portion of this project, a thorough analysis was done on the existing wall, roof and corner condition of the current most common typology present in the 9-story prefabricated concrete apartment building. After a comprehensive evaluation, several levels of design development were created and tested in comparison to the original condition and in comparison to each other in order to determine the ideal design form. The different design development options are evaluated using Therm 7.3, a computer energy transfer program. Therm is able to measure the thermal performance of the materials and visually demonstrate how thermal energy passes through the material.

Design Introduction

Russia's challenge creating an affordable design solution that can improve the exterior insulation and energy efficiency of the building is very complicated. There were some good options generated by VTT Technical in their most recent retrofit study, but those options still fall short in many areas in terms of creating a better, more adaptable, less expensive, easier to install, more sustainable, lower lifetime maintenance exterior insulation system. The proposed design improves on VTT Technical's approach in all of the above mentioned design criteria. A prefabricated insulated panel will create a far more aesthetically appealing building envelope design than any of the previous retrofit designs.

As stated earlier, this thesis proposes the use of a fiber cement prefabricated panel with a cellulose insulation interior. However, as this material combination has not been attempted in the past, a new insulated panel had to be created. In order to do

this, I first investigated the thermal performance of the existing exterior wall condition to make a quantitative comparison to the material assembly that I was developing. The next step in the investigation addressed the need for a prefabricated panel that would have connection points. In addition, at these connection conditions, thermal bridging complications occurred because the connections had a far lower R-value than the rest of the panel and as such needed to be addressed.

The investigation led to a final design solution that can properly insulate the exterior of the building and do so in a manner that is more adaptable, less expensive, easier to install, more sustainable, has a lower lifetime maintenance exterior insulation system. Finally, I have determined that applying this new material assembly to the exterior of an existing façade in Volzhsky would result in improvement in building energy efficiency and aesthetics.

Initial Investigation

In order to create a proper design solution, the existing building envelope thermal insulation values had to be established. The original condition had already been measured in previous retrofit studies. Existing walls, windows, roofs, and basements were tested by VTT Technical and found to have a total U-value of 0.9 or a total R-value of 5.12 °F hr/Btu. However, measuring the actual performance of the materials themselves needed to be done in order to establish a baseline for improvement. By using “Therm 7.3” a computer energy transfer program, the thermal performance of the materials could be measured and visually demonstrated. Figure 7.1 shows the temperature gradient through the exterior. The exterior surface of the wall is approximately -10 degrees when the exterior air temperature is -25 degrees. The exterior temperature of the wall is warmer than the actual air temperature because of heat transfer from the interior of the wall to the exterior. Heat transfers both directions

Figure 7.1: Existing Wall Thermal Efficiency Condition

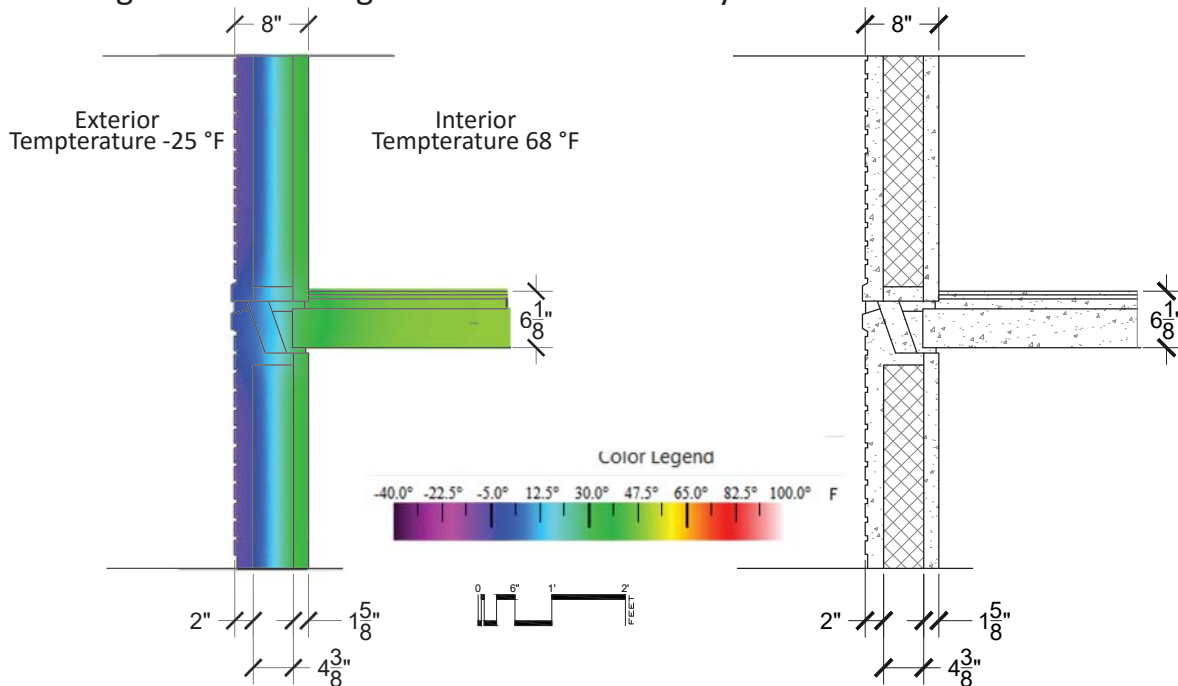
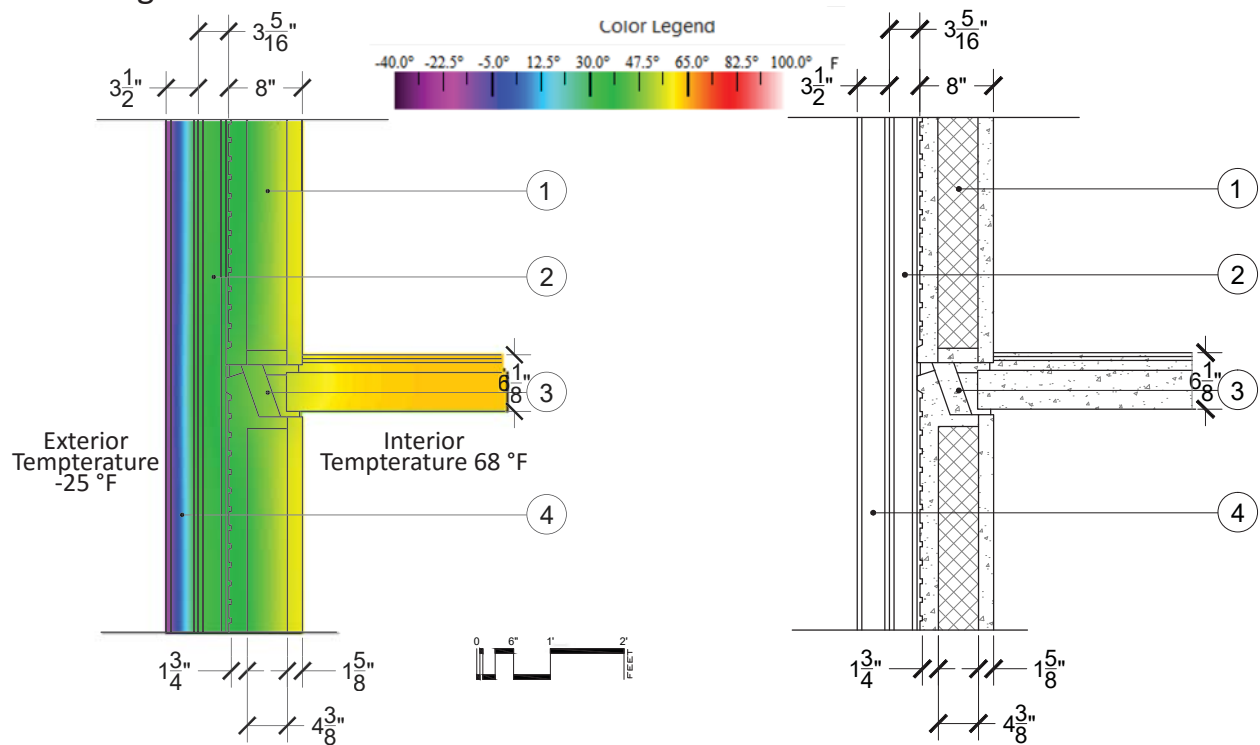


Figure 7.2: Basic Exterior Wall Insulated Prefab Panel Retrofit



1. EXISTING RUSSIAN PREFABRICATED CONCRETE SANDWICH PANEL

2. AIR GAP AND METAL FRAME TO ATTACH PANELS TO WALL

3. EXISTING RUSSIAN PREFABRICATED CONCRETE PANEL FLOOR AND JOINT CONDITION

4. NEW PREFABRICATED INSULATED FIBER CEMENT PANEL

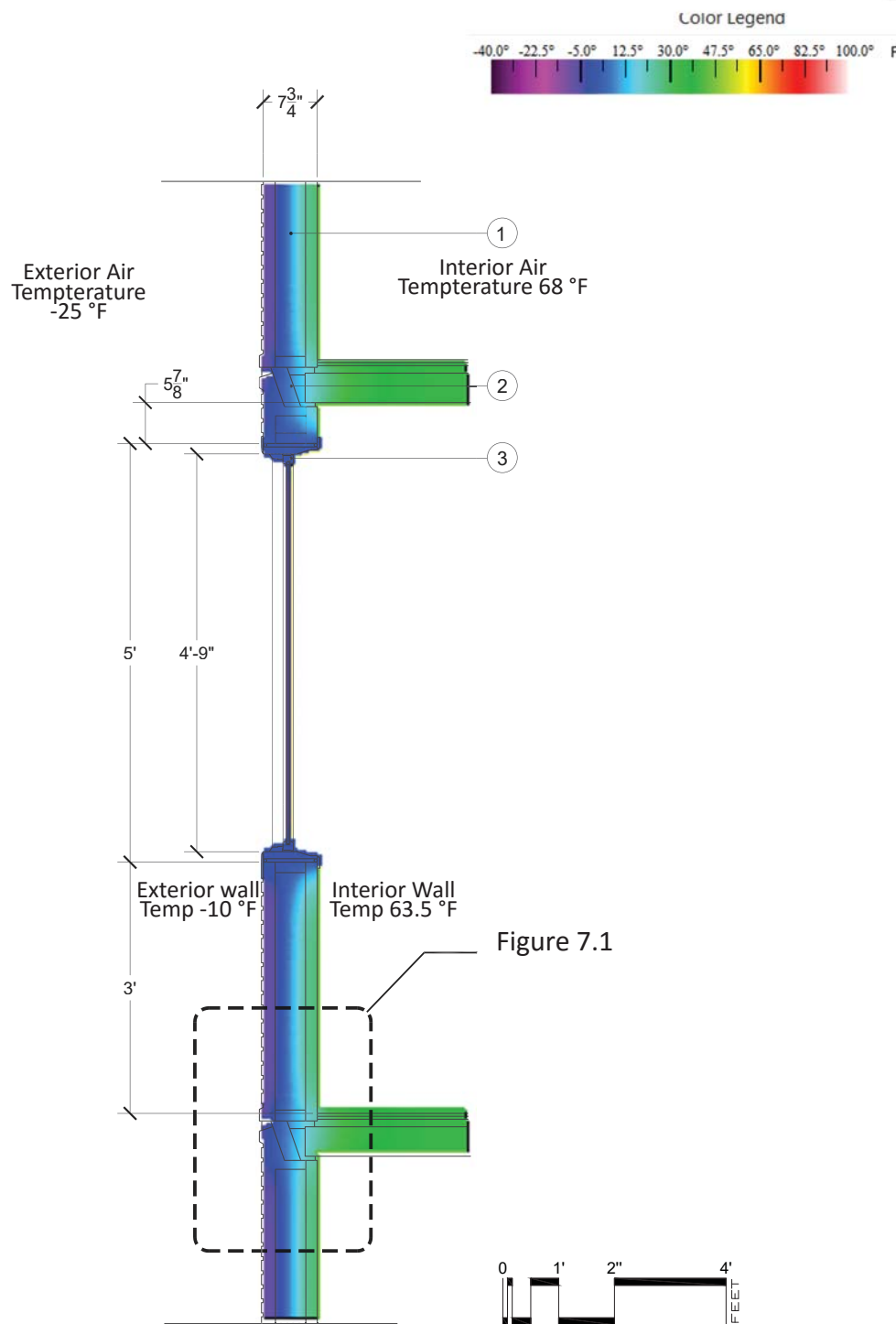
through the wall, the cold will penetrate the interior of the space and the heat will leak toward the exterior of the wall as well. The interior surface is approximately 49.5 degrees with an internal air temperature of 68 degrees Fahrenheit.

The diagram in Figure 7.1 serves as a baseline from which we can measure the improvement of the new material retrofit application. Figure 7.2 shows the temperature gradient through the exterior wall after the new material assembly is attached to the exterior wall. In this diagram, the effect of applying a continuous fiber cement panel with cellulose insulation to the exterior of the building façade. The interior wall temperature now is approximately 63.5 degrees which is an overall increase of 14 degrees on the interior of the wall. As minimal thermal comfort occurs at approximately 68 degrees according to ASHREE standards¹, the overall energy needed to heat the space would be reduced by 76 percent. This is calculated by taking the difference of the minimal desired temperature of the actual wall temperature of the two different interior wall conditions and dividing them by each other ($49.5^{\circ} - 68^{\circ} = 18.5^{\circ}$ and $63.5^{\circ} - 68^{\circ} = 4.5^{\circ}$, $(4.5^{\circ} / 18.5^{\circ}) - 1 = 76\%$). This is a substantial improvement that is accomplished simply by increasing the exterior insulation R-value to the existing code of approximately R-15. However, this is not unexpected as increased thermal efficiency is the intended outcome of increase insulation levels.

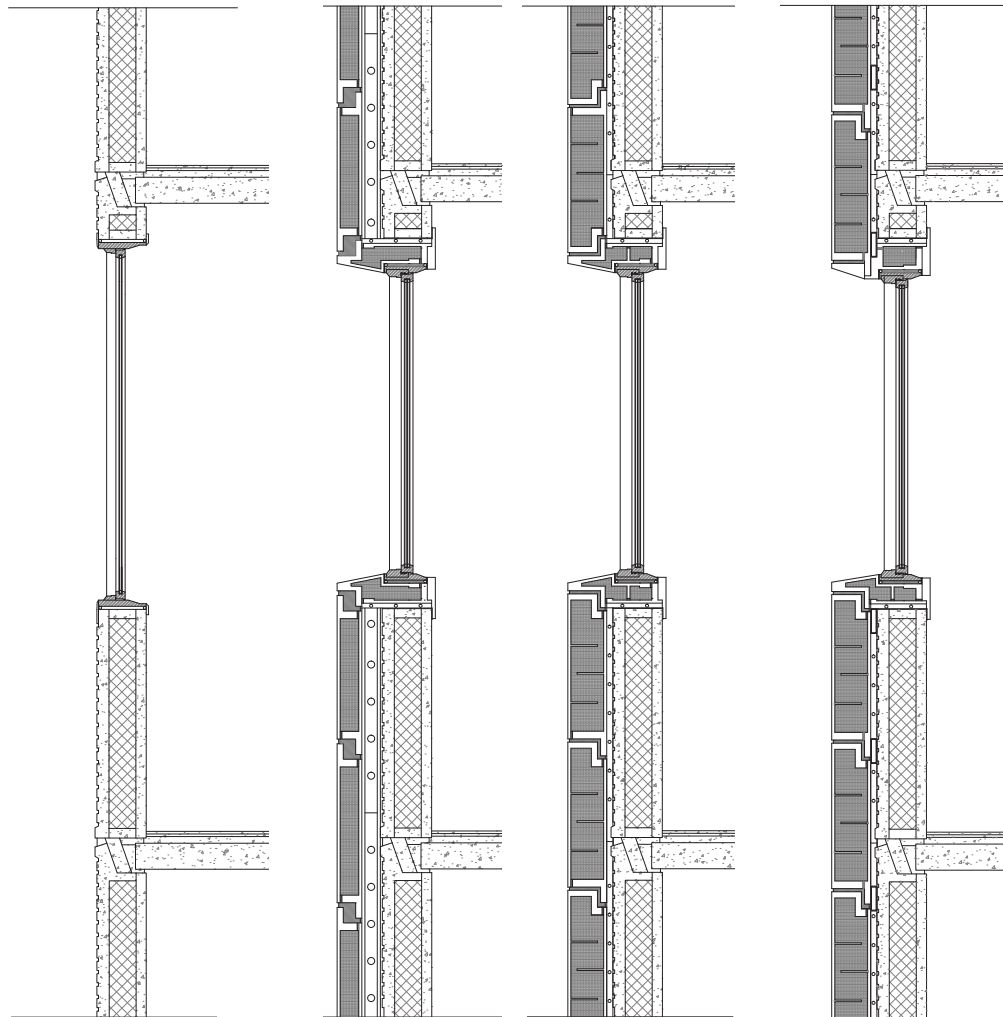
Now that a proper baseline has been established, investigating the prefabricated panel system with the Therm program shows thermal bridging at the connection points are the areas that need to be addressed when dealing with an exterior façade system. Another important factor to consider is that these buildings have a window in every panel (with exception of some end units) which impacts the thermal performance of the entire panel. As stated earlier, the typical apartment had three window typologies. A small window in bedrooms, a larger window in living rooms and a balcony window

¹ "Psychrometric Chart: ASHREE Standard 55-2004 Using PMV," Climate Consultant 6.0, November 18, 2014

Figure 7.3: Existing Full Wall R-Value 5.12



1. RUSSIAN PREFABRICATED CONCRETE S,
2. RUSSIAN PREFABRICATED CONCRETE P,
JOINT CONDITION.
3. RUSSIAN DOUBLE PANE WINDOW (U-VAL



condition which in most apartments may have a sliding glass door as well. For the purposes of testing, only the walls with small windows will be examined as they represent the most consistent exterior condition in most of the panels. This small bedroom window takes up around 28 percent of the total panel area and therefore is a location for substantial heat loss if not accounted for in the calculations. Figure 7.3 shows an entire wall section of one panel that has been examined in the Therm program to establish a baseline.

Design Development

Now that the baselines have been established, it is important to test the initial

Figure 7.4: Fiber Cement Panel R16

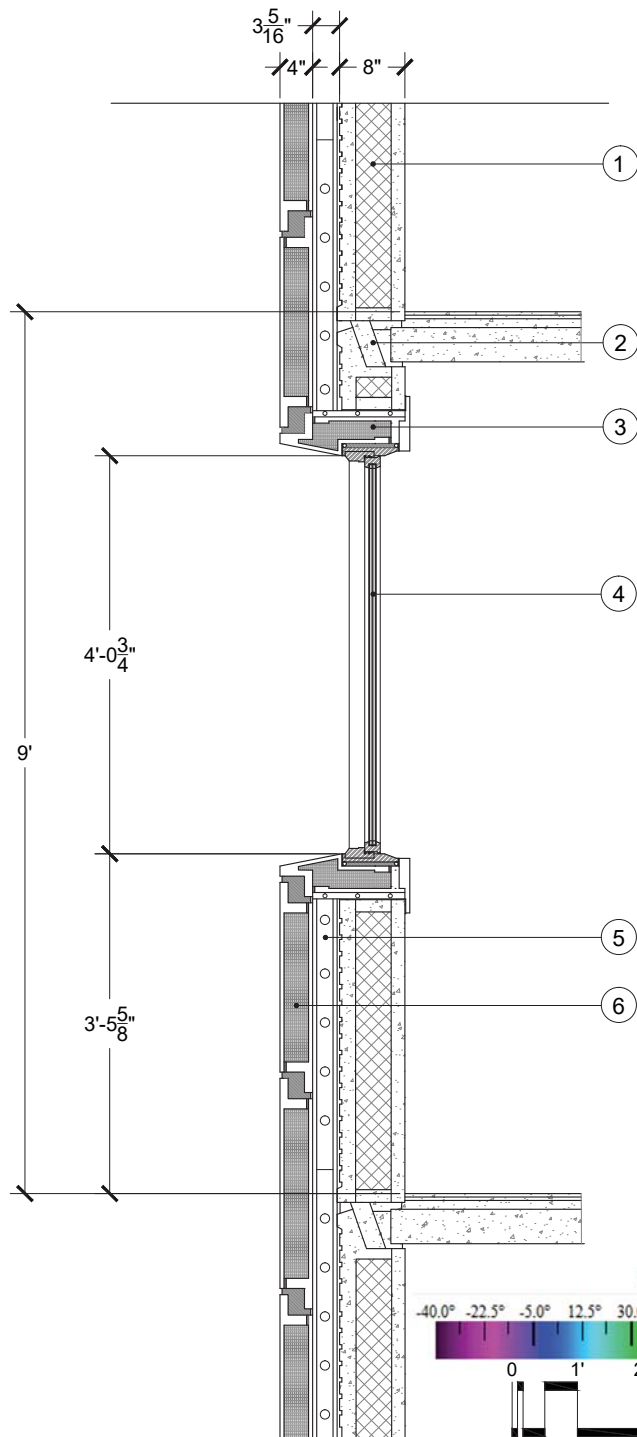
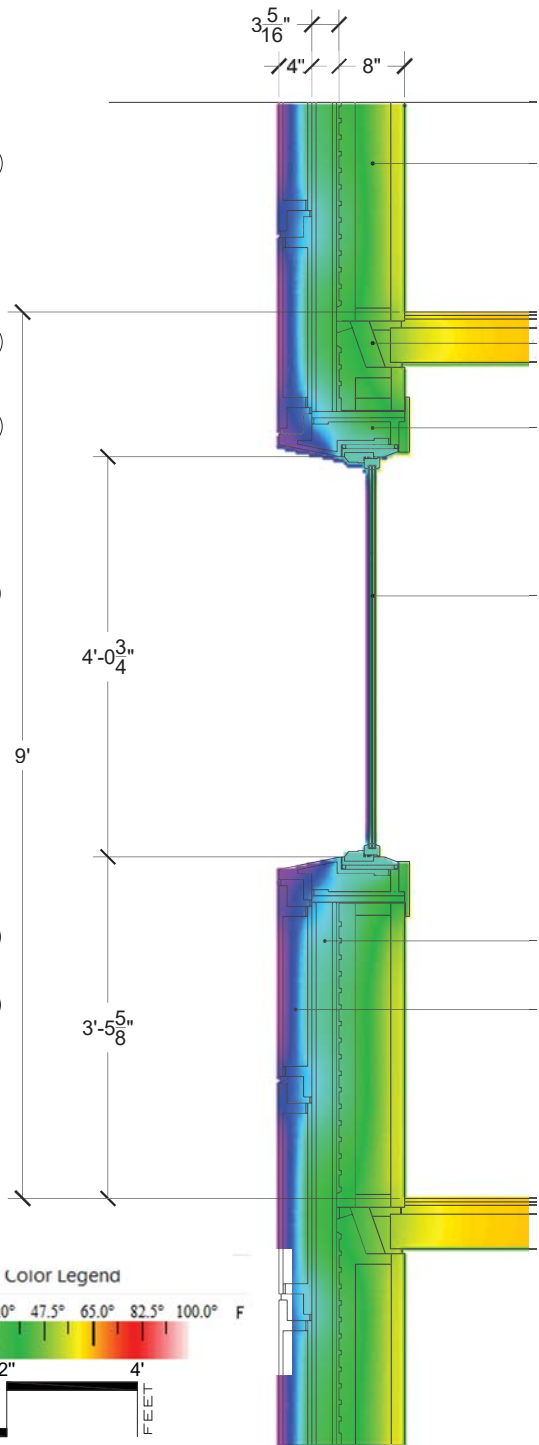


Figure 7.5: Panel R16 (Therm)



1. EXISTING RUSSIAN PREFABRICATED CONCRETE SANDWICH PANEL
2. EXISTING RUSSIAN PREFABRICATED CONCRETE PANEL FLOOR AND JOINT CONDITION.
3. NEW PREFABRICATED FIBER CEMENT WINDOW FRAME
4. NEW TRIPLE PANE, ARGON FILLED, LOW E GLASS OPERABLE WINDOW.
5. NEW PREFABRICATED INSULATED FIBER CEMENT PANELS
6. CELLULOSE INSULATION INTERIOR

design forms of the prefabricated panel. There are very specific design criteria that had to be established and specific limitations of the materials used that had to be overcome before the application could be tested. The basic design criteria are that the panel be made of fiber cement and cellulose insulation. This design factor has inherent challenges, as cellulose insulation typically comes in one of two forms, loose fill or spray in. Neither form can support itself and must be supported by the wall cavity. Additionally, neither form can be exposed to moisture and weather without substantial deterioration. This creates the need for a self-contained system that completely encloses the cellulose insulation and protects it from deterioration.

The new panel design consists of a completely enclosed fiber cement container with cellulose insulation on the interior. However, this design creates new design challenges in both installation and thermal bridging. Thermal bridging is when heat flows through a more conductive/less insulating material often bypasses the insulation. R-value in a wall assembly is the sum of the overall R-value of the components in that wall. If too many thermal bridges occur they conduct heat through the wall, then the insulation becomes far less effective. To address the thermal bridging of the fiber cement which has a much lower R-value(between 0.5-1 per inch) than cellulose insulation (between 3-3.7 per inch), a closed cell urethane foam pad is placed where then panels connect as shown in Figure 7.5, thus minimizing the thermal bridging and improving the insulation value at the connection points.

The next design challenge is the method of installing the new panel material to the façade. Insulated panels currently produced on the market typically attach rigid insulation to the exterior of the façade. This is possible when using a rigid insulation but not when using this new panel form with cellulose insulation. This is because the current industry standard has the insulation on the back side of the panel allowing them to create a continuous insulation across the façade. The exterior of the panel is just for

weather proofing and aesthetic appeal. To install this new panel system, I designed an overlapping system to attach the new panels to the façade.

The new design will have a fiber cement lip that is on top and bottom in an L-shape. This will create an attachment point to the façade that can be screwed down. The opposite side of the panel will lock in place and be secured with silicone sealant and glue. Figure 7.4 shows an initial design form of the new panel in section on the building façade. As the current windows are areas of significant heat loss, the new application will have the new window sill made from a prefabricated fiber cement and cellulose insulation window frame to improve the thermal insulation at the window. In addition, the existing windows will be replaced with the triple pane window argon gas filled with 2 low-e glazing film as specified by VTT Technical as this is the best window application possible with a new U-value of 1 BTU/hr/ft²/°F.

Figure 7.5 shows the thermal performance of the new exterior insulation prefabricated wall panel with an R-16 insulation value, effectively improving the interior wall temperature from 49.5 degrees Fahrenheit to 63.5 degrees. This new wall panel design is fairly successful at minimizing thermal bridging at the joints, but still needs improvement. In addition, as R-15 is the minimum standard for Russian code for overall wall assembly in this region I concluded that the wall insulation levels should be increased. One complication that occurs is that with thicker insulation panels there is a need for an internal structure for stability and strength. This is accomplished in a later iteration by placing ribs on the interior of the panel to increase its structural rigidity. In order to improve on the thermal bridging, a thermal break using a urethane pad is installed between the exterior portion and interior portion of the panel. Minimizing thermal bridging is especially important as the panel grows in thickness. By increasing the R-value from R-5.12 to R-16 ft² °F hr/Btu, the interior wall temperature went from 49.5 °F to 63.5 °F and improved the total energy to heat the space to 68 °F by 76 percent.

Figure 7.6 shows the next iteration of the panel design with a thicker cross section of insulation. The air gap is lessened due to the fact that an air gap is only needed to be a minimum of 1 inch and R-values are not improved with increased size. The new R-value of the wall is approximately R-27. By increasing the R-value from R-5.12 to R-27 $\text{ft}^2 \text{ } ^\circ\text{F hr/Btu}$, the interior wall temperature went from 49.5 $^\circ\text{F}$ to 64.5 $^\circ\text{F}$ and improved the total energy to heat the space to 68 $^\circ\text{F}$ by 81 percent.

In addition, new interior fiber cement fins have been included to increase the stability of the panel. Finally, the joint condition has been altered with a thinner thermal urethane foam pad and as the panel is thicker the cellulose is used further in the panel joint. Figure 7.7 shows the new thermal analysis of the fiber cement panel. One very clear area of improvement needed, is that the new fins on the interior of the panel are creating thermal bridges that are really affecting the overall performance of the panel. This must be addressed in the next iteration of the design.

Final Form of New Exterior Insulated Panel

Now that the majority of the shortcomings have been worked out of the panel form, a viable design solution has taken shape. To fix the thermal bridging that occurred in the interior of the panel, the fins were replaced with a high density urethane connecting pad that is secured to the interior. This improves thermal bridging and strengthens the structure of the panel. The new panel wall section is shown in Figure 7.8 and the thermal performance of that wall section is shown in Figure 7.9. Figure 7.10 shows the design development and thermal performance improvements for comparison to the original wall performance levels.

New Exterior Insulated Panel Specifications

The new insulated fiber cement panel will improve the building envelope

Figure 7.6: Fiber Cement Panel R27

Figure 7.7: Panel 2.0 R27 (Therm)

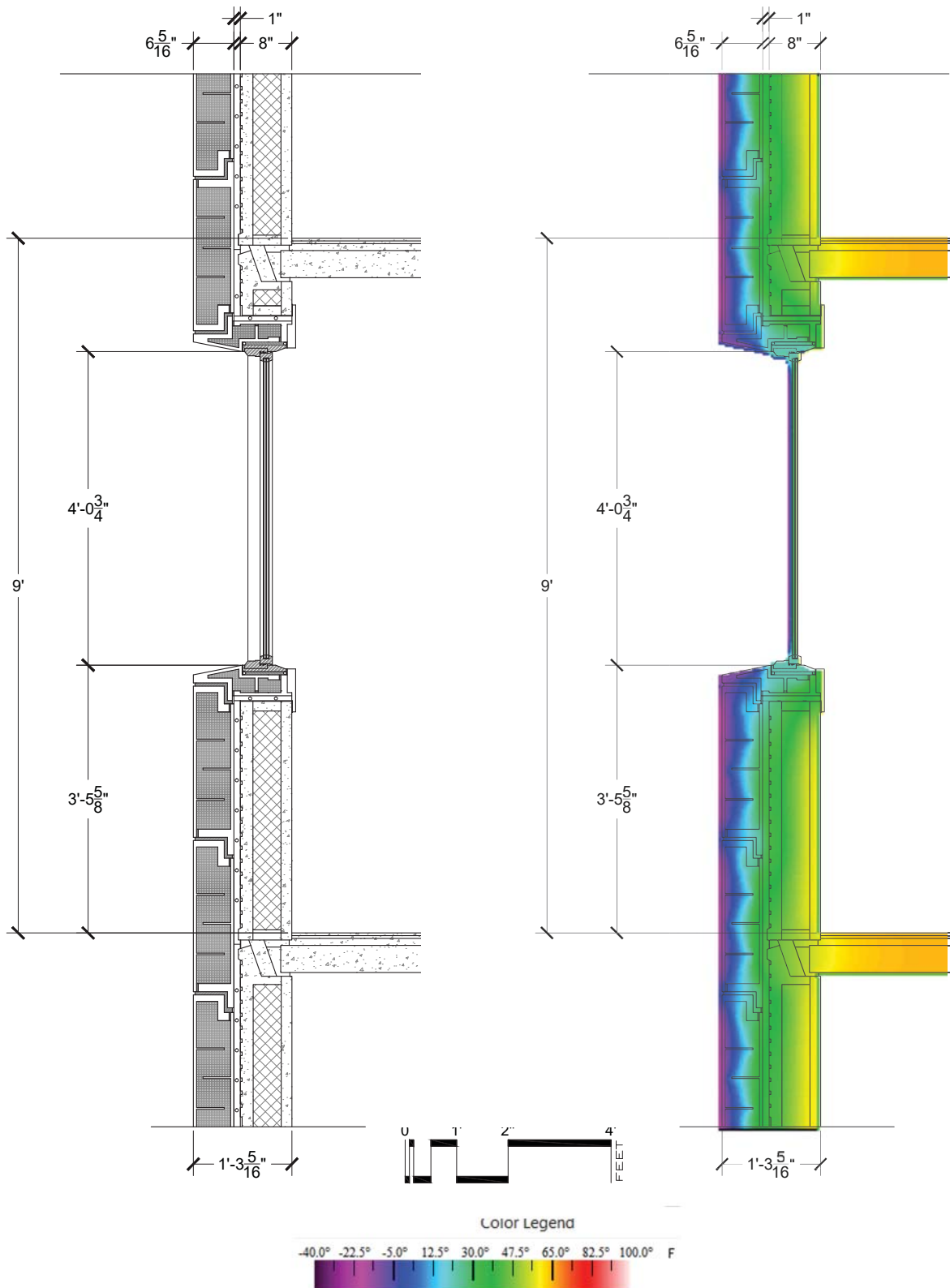
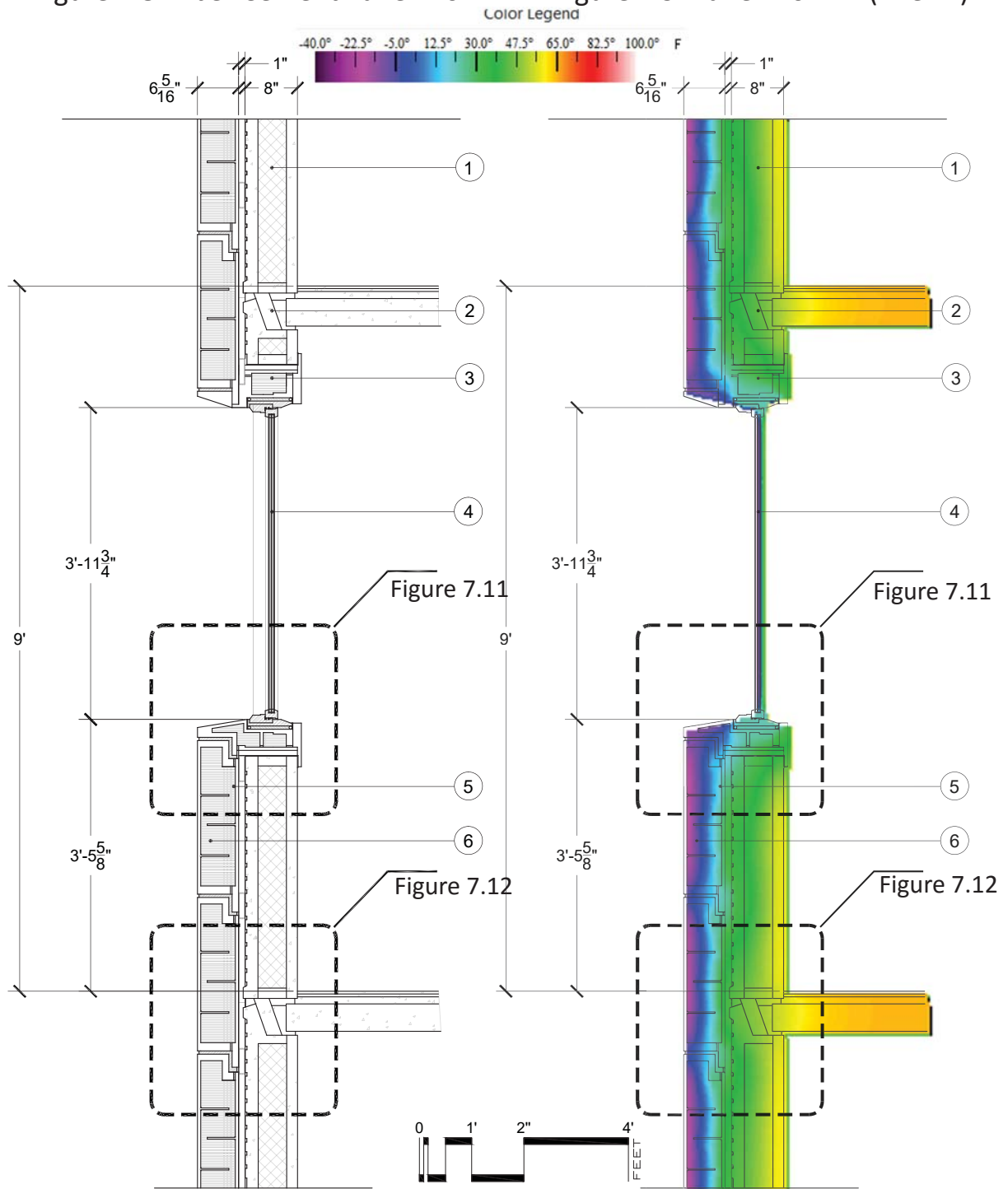


Figure 7.8: Fiber Cement Panel 2.0 **R27** Figure 7.9: Panel 2.0 **R27** (Therm)

1. EXISTING RUSSIAN PREFABRICATED CONCRETE SANDWICH PANEL
2. EXISTING RUSSIAN PREFABRICATED CONCRETE PANEL FLOOR AND JOINT CONDITION.
3. NEW PREFABRICATED FIBER CEMENT WINDOW FRAME
4. NEW TRIPLE PANE, ARGON FILLED, LOW E GLASS OPERABLE WINDOW.
5. NEW PREFABRICATED INSULATED FIBER CEMENT PANELS
6. CELLULOSE INSULATION INTERIOR

Figure 7.10: Exterior Insulation Panel Development

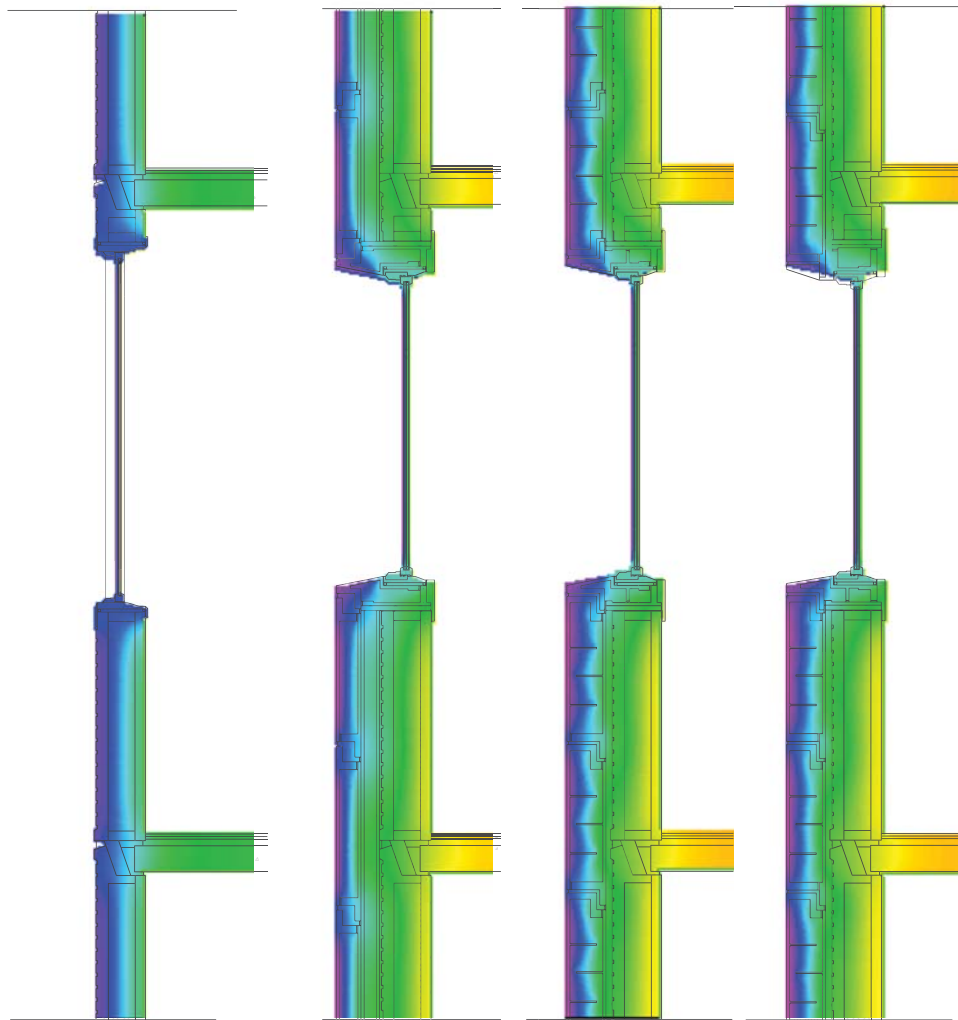
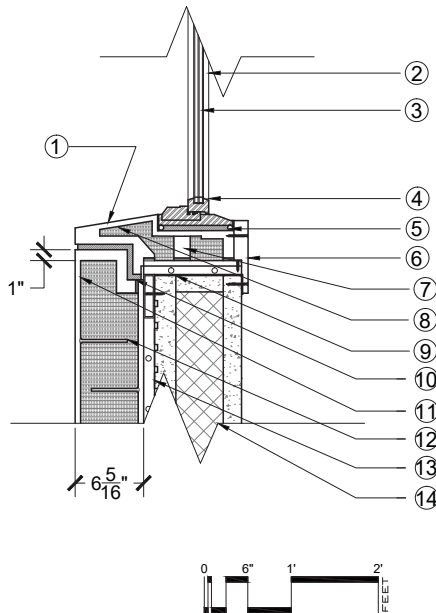
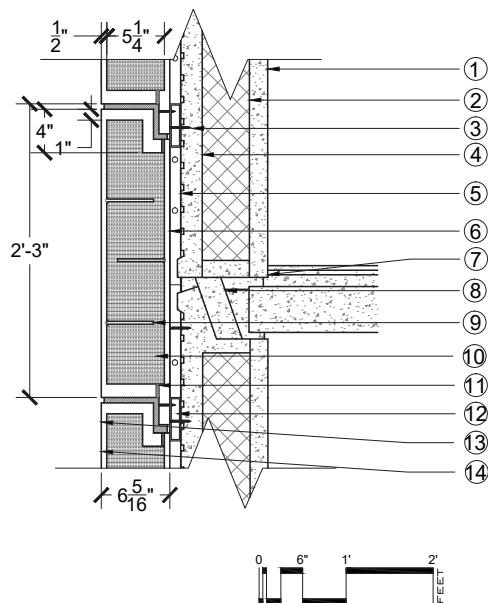


Figure 7.11: Window Detail



1. MANUFACTURE ASSEMBLED PREFABRICATED FIBER CEMENT WINDOW SILL AND FRAME WITH PRE-INSTALLED WINDOW.
2. PAINTED ALUMINUM WINDOW FRAME
3. TRIPLE PANE WINDOW ARGON GAS FILLED WITH LOW-E FILM ON BOTH INTERIOR AND EXTERIOR
4. MANUFACTURE INSTALLED SLIDING INTERIOR WINDOW FRAME
5. SILICONE SPACERS ON BED OF SILICONE
6. INTERIOR PREFABRICATED FIBER CEMENT WINDOW TRIM FASTENED TO NEW PREFABRICATED FIBER CEMENT INSULATED WINDOW PANEL FRAME WITH $\frac{1}{4}$ " SCREWS
7. PREFABRICATED FIBER CEMENT INSULATED WINDOW PANEL FRAME WITH CELLULOSE INSULATION
8. SLOPE AWAY FROM WINDOW FOR WATER EVACUATION
9. HOLLOW ALUMINUM FRAME ON TOP OF FIELD APPLIED A VAPOR BARRIER, SECURED TO EXISTING WINDOW OPENING IN PREFABRICATED RUSSIAN CONCRETE WALL PANEL
10. URETHANE CLOSED CELL FOAM CONNECTION PAD BETWEEN PANELS FOR WATER PROOFING, MINIMIZING THERMAL BRIDGES AT CONNECTIONS AND IMPROVED INSULATION AT THE JOINT CONDITION
11. EXTERIOR FACE OF PREFABRICATED FIBER CEMENT PANEL- CAN BE FORMED INTO ANY FORM OF FINISH OR COLOR
12. INTERIOR HIGH DENSITY URETHANE FIN FOR INTERIOR STABILITY
13. HOLLOW ALUMINUM FRAME ON TOP WITH 1 INCH AIR GAP SECURED TO EXISTING PREFABRICATED RUSSIAN CONCRETE WALL PANEL. PREFABRICATED FIBER CEMENT PANELS BOLT TO FRAME
14. EXISTING PREFABRICATED CONCRETE SANDWICH PANEL WITH 4 INCHES OF INSULATING CONCRETE AND 2 INCHES OF STRUCTURAL CONCRETE ON EXTERIOR

Figure 7.12: Wall Detail



1. 2 INCH INTERIOR STRUCTURAL CONCRETE (ORIGINAL PREFABRICATED RUSSIAN PANEL)
2. INSULATING CONCRETE 4 INCHES THICK WITH R-VALUE BETWEEN 0.8 - 0.9 PER INCH
3. $\frac{1}{4}$ " SCREW SECURES ALUMINUM VERTICAL SUB GRID FRAME TO EXISTING CONCRETE FACADE @ 16" O.C.
4. 2 INCH EXTERIOR STRUCTURAL CONCRETE (ORIGINAL PREFABRICATED RUSSIAN PANEL)
5. HOLLOW ALUMINUM FRAME ON TOP SECURED TO EXISTING PREFABRICATED RUSSIAN CONCRETE WALL PANEL CREATING VERTICAL SUB GRID WITH SPACING @ 2'6" O.C. PREFABRICATED FIBER CEMENT PANELS BOLT TO FRAME
6. INTERIOR FACE OF PREFABRICATED CEMENT PANEL. BOLTED TO ALUMINUM FRAME
7. ORIGINAL CONCRETE FLOOR
8. JOINT CONDITION OF ORIGINAL RUSSIAN PREFABRICATED WALL MORTARED IN PLACE
9. INTERIOR HIGH DENSITY URETHANE FIN FOR INTERIOR STABILITY
10. CELLULOSE INSULATION PRE-INSTALLED DURING THE MANUFACTURING PROCESS
11. URETHANE THERMAL BREAK WITH SILICONE SEALANT ON BOTH SIDES
12. METAL SCREWS FASTEN FIBER CEMENT PANEL TO FRAME
13. URETHANE CLOSED CELL FOAM CONNECTION PAD BETWEEN PANELS FOR WATER PROOFING, MINIMIZING THERMAL BRIDGES AT CONNECTIONS AND IMPROVED INSULATION AT THE JOINT CONDITION
14. EXTERIOR FACE OF PREFABRICATED FIBER CEMENT PANEL- CAN BE FORMED INTO ANY FORM OF FINISH OR COLOR

insulation value. The window and wall section details are in Figures 7.11 and 7.12.

These details show the materials, assemblies and dimensions of the new fiber cement panel. To minimize expense of the new window installation the entire window assembly is prefabricated and installed as a single piece on site. The manufacturer will cast and construct the fiber cement frame with an extended sill for a proper drip edge. Then the new window will be installed, into the frame prior to delivery to the site. This will create a decrease in the cost to install the new windows. At the site the contractor will simply install the metal frame to the exterior of the building and window openings. Then simply snap and bolt the panels onto the side of the building. The system is designed to install quickly and minimize cost.

Figure 7.13 shows the construction material specifications for one panel. In addition, a complete material assembly is shown in Figures 7.14 and 7.15. In these

Figure 7.13: Fiber Cement Panel Specifications

Fiber Cement (Density:350 kg/m³):

Cross Section Area = $22.14 \text{ in}^2 + 20.51 \text{ in}^2 = 42.65 \text{ in}^2 = 0.296 \text{ ft}^2$

Total Volume = $0.296 \text{ ft}^3 \times 5 \text{ ft} = 1.48 \text{ ft}^3 = 0.0419 \text{ m}^3$

Fiber Cement Total Mass= 14.67 kg

Insulation (Density:56kg/m³):

Cross Section Area = $103.42 \text{ in}^2 = 0.718 \text{ ft}^2$

Total Volume = $0.718 \text{ ft}^2 \times 5 \text{ ft} = 3.905 \text{ ft}^3 = 0.112 \text{ m}^3$

Mass= 6.72 kg

Urethane Thermal Barrier (Density:30kg/m³):

Cross Section Area = $.31 \text{ in}^2 + .31 \text{ in}^2 = .62 \text{ in}^2 = 0.004 \text{ ft}^2$

Total Volume = $0.004 \text{ ft}^2 \times 5 \text{ ft} = 0.02 \text{ ft}^3 = 0.00057 \text{ m}^3$

Mass= 0.0171 kg

Urethane Joint Between Top and Bottom Panels (Density:30 kg/m³):

Cross Section Area = $4.21 \text{ in}^2 = 0.029 \text{ ft}^2$

Total Volume = $0.029 \text{ ft}^2 \times 5 \text{ ft} = 0.145 \text{ m}^3 = 0.0041 \text{ m}^3$

Mass= 0.123 kg

Typical Panel Weight= 21.53 kg = 47.47 lbs

Typical Wall Original Weight = 682 - 800 kg or 1499 -1763 lbs

New Panel Roughly Increasing Overall Wall Weight by Around 10%

exploded axonometric views, the overall form and assembly is more clearly shown.

Figure 7.16 shows a ghosted view of the completed panel and Figure 7.17 shows the same panel, but is opaque. It should be noted that all views are from the back side of the material as this is where all the construction details will be concealed and the front of the material will be left clean and allow for a seamless and aesthetically appealing form and finish.

The panel can take on any dimensional form but the standard form to be applied to the Russian social housing buildings is a 2'-3" x 5'-0" panel as this will fit best within the current prefabricated grid system of the 9-story typology in Volzhsky. But the panels can be adjusted in size to fit the aesthetic desires of design. For a panel that is 2'-3" x 5'-0" the typical panel weight is around 47 lbs. This is a weight that can easily be installed by two people onto the façade without a crane or heavy equipment. The only equipment needed would be a scissor lift or other form of lightweight easily maneuverable lifting system that can get the people to the higher floor levels. As the building is only 9 stories, a scaffolding system would also work very effectively. The panels light weight design creates a variety of application options.

Design Application

Now that an alternative material system has been designed that improves upon VTT Technical's design and satisfies all the criteria for thermal improvement, the next step is to apply this new exterior insulation system to the exterior of the selected social housing apartment building in Volzhsky. Due to the repetitive nature of the building design, applying this new insulation panel to just one 9-story 4 unit floor plan building at Volzhsky, UL, Druzhby 48 (18 M/R-N) is all that is necessary to show façade application. Modeled in Figure 7.18, is the original unaltered building façade prior to adding the new material. Figure 7.19, shows what the building would look like with just the basic fiber

Figure 7.14: Panel Exploded Axonometric

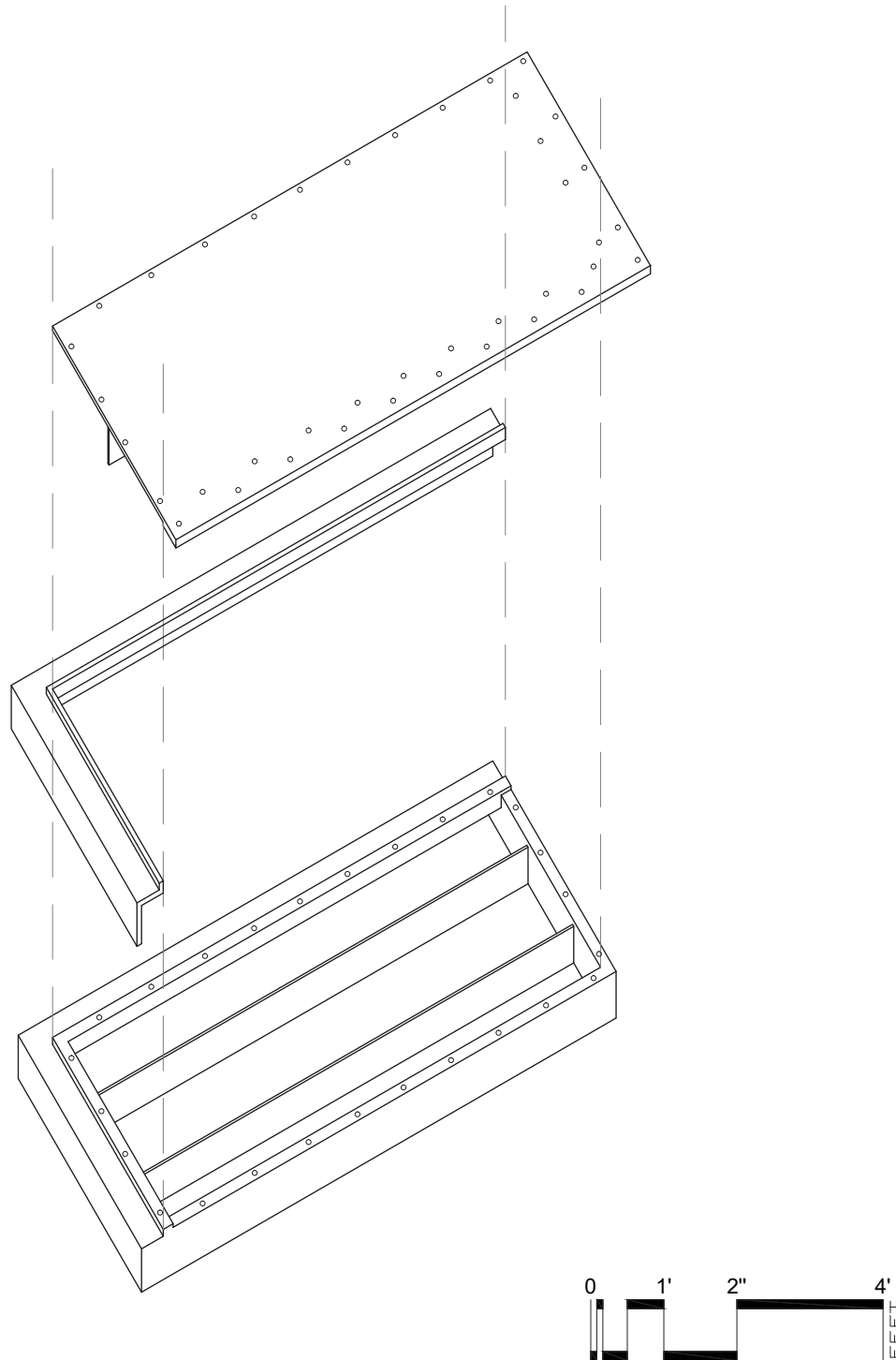
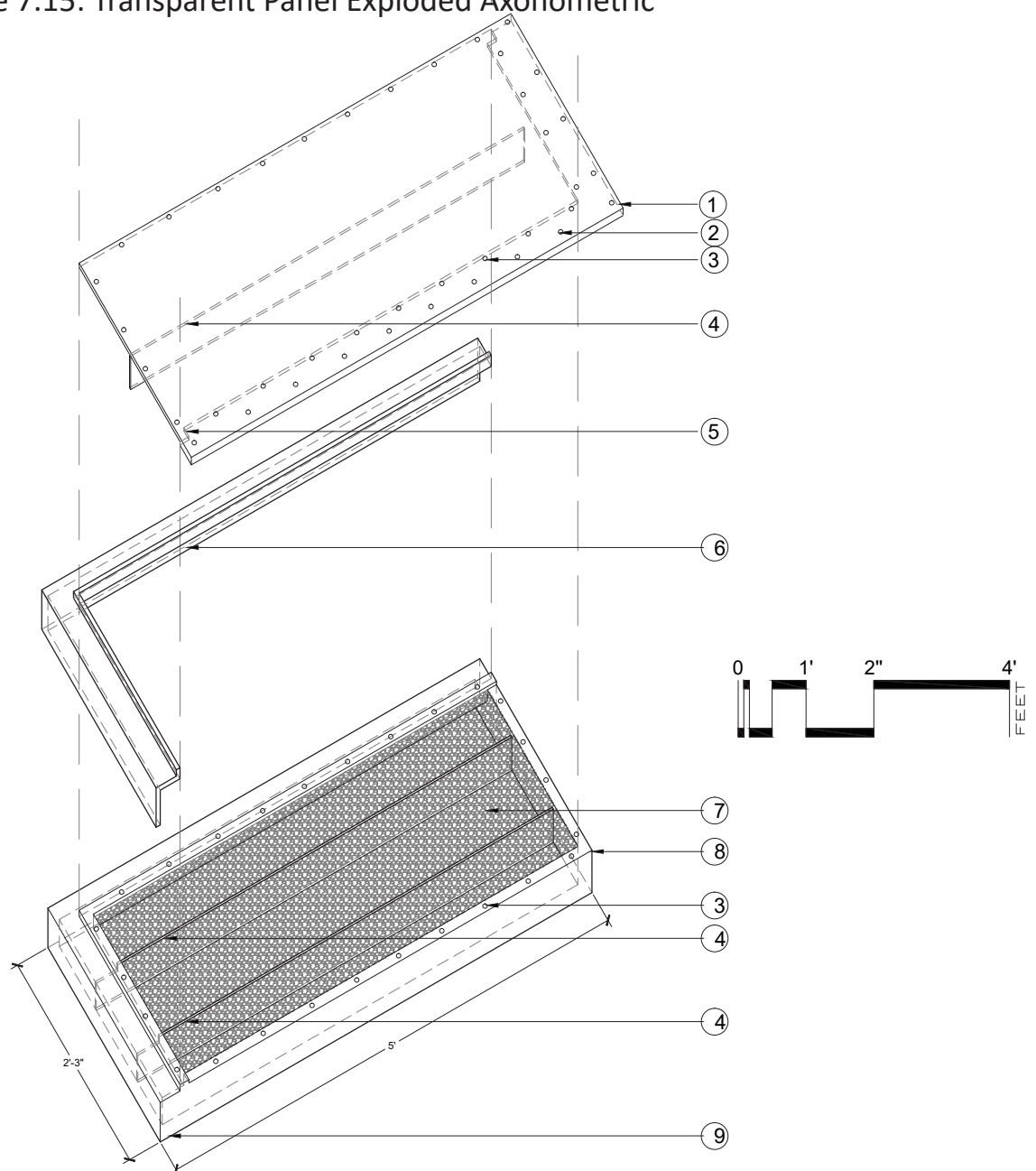


Figure 7.15: Transparent Panel Exploded Axonometric



1. BACKSIDE OF PREFABRICATED FIBER CEMENT PANEL
2. BOLT LOCATIONS TO FASTEN PANEL TO ALUMINUM FRAME ON THE EXTERIOR OF THE BUILDING
3. BOLT LOCATIONS THAT FASTEN THE TWO PIECES OF THE PANEL TOGETHER WITH URETHANE THERMAL BREAK AT THE CONNECTION INTERIOR HIGH DENSITY URETHANE FIN FOR INTERIOR STABILITY
4. FIBER CEMENT FIN TO STABILIZE THE INTERIOR OF THE PANEL
5. 1/2" JOINT STEP DOWN
6. URETHANE CLOSED CELL FOAM CONNECTION PAD BETWEEN PANELS FOR WATER PROOFING, MINIMIZING THERMAL BRIDGES AT CONNECTIONS AND IMPROVED INSULATION AT THE JOINT CONDITION
7. CELLULOSE INSULATION WET APPLIED
8. EXTERIOR PREFABRICATED FIBER CEMENT PANEL WITH INTERIOR FLUID APPLIED WATER PROOFING COATING TO MAKE WATER TIGHT.
9. FACE OF EXTERIOR PREFABRICATED FIBER CEMENT PANEL (MANY FORMS, FINISH OR COLORS)

Figure 7.16: Transparent Panel Axonometric

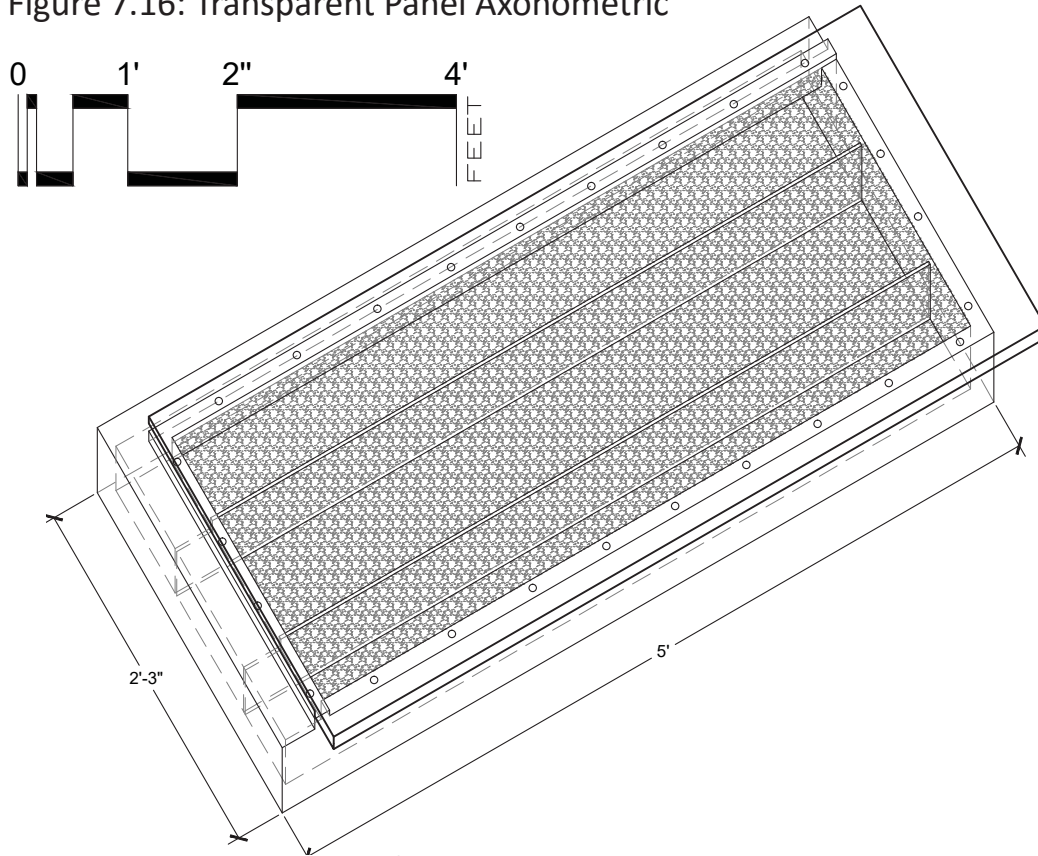
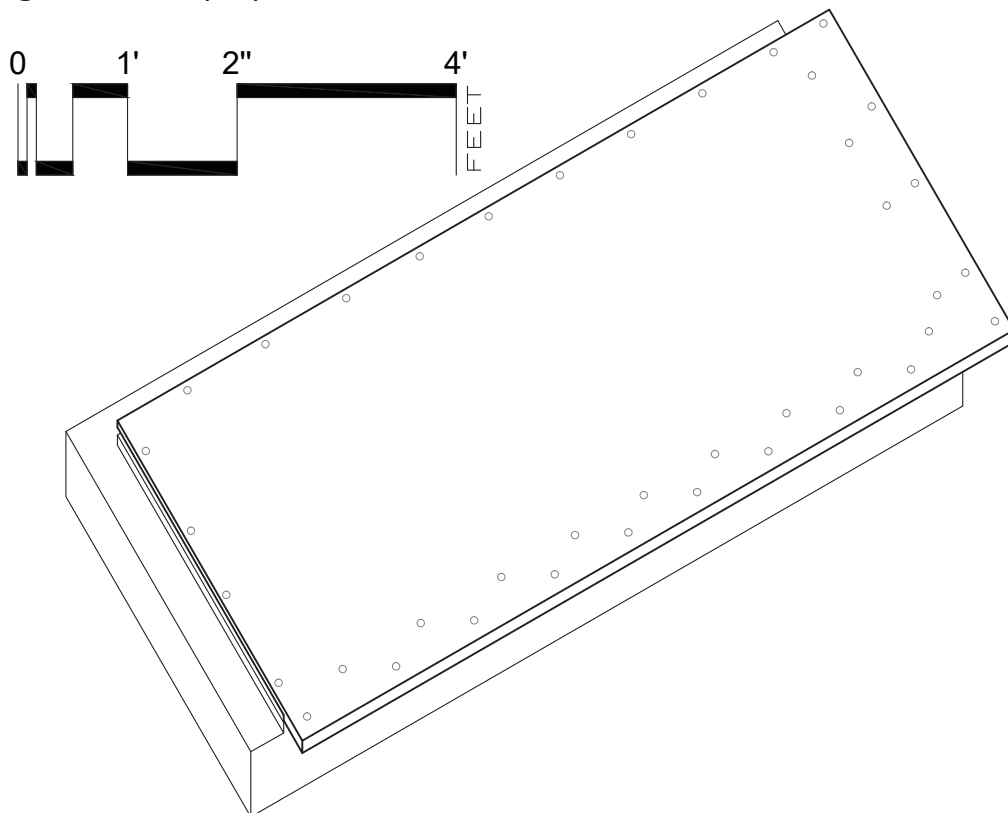


Figure 7.17: Opaque Panel Axonometric



cement finish in a charcoal color.

Fiber cement has incredible variation potential for the exterior of these buildings. Owners and associations will be able to choose colors, and finishes that are specific to their own personal design aesthetic. Figure 7.20 shows some of the different varieties of current finishes from a variety of manufactures available today. The most common finish is the wood imitation finish, as fiber cement is used most commonly on the exterior of a house as an imitation wood plank. However, there are many more finishes and styles on the market for a variety of functions. As Fiber cement can be molded and colored into many shapes and finish the possibilities are virtually limitless.

These finishes could all be applied to the exterior of this new fiber cement panel and could be modified or combined to create new finish variations. Figures 7.21 and 7.22 show a close up of the building and new fiber cement panel options with a window condition. Figures 7.23 and Figure 7.24 demonstrate possible variations by altering the exterior finish of the panel to something that resembles stone during the manufacturing process. The new material is not only compositionally a better alternative to the VTT Technical's recommendation of mineral wool and plaster coat finish, but it also is very aesthetically appealing and creates the ability to mass produce a building exterior that can have different façade finishes allowing for these buildings to be more unique and appear less repetitive.

Figure 7.18: Unaltered 9-Story Building Typology Rendering



Figure 7.19: New Facade on 9-Story Building Typology



Figure 7.20: Fiber Cement Finishes



<http://www.hometechexterior.com/siding/siding-material-comparison/>



<http://www.lakeflatodogrun.com/inspirations/the-lick-list/>



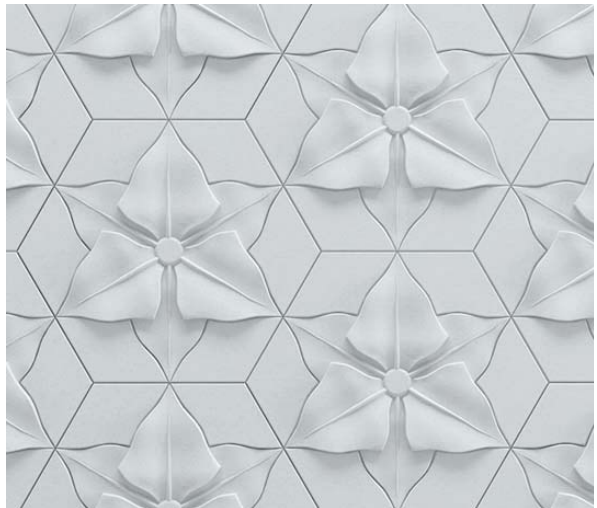
<http://zjgleader.manufacturer.globalsources.com/si/6008839643650/pdtl/Wall-panel/1065438378/Fiber-Cement-Wall-Panels.htm>



<http://www.archiproducts.com/en/products/154608/concurrent-constellations-fiber-cement-3d-wall-tile-quadilic-kaza-concrete.html>



<http://www.frbiz.com/image-wall-tile-marble-texture>



<http://www.trendir.com/archives/textural-concrete-tiles-with-relief-motifs.html>

Figure 7.21: Unaltered Window Area



Figure 7.22: New Fiber Cement Panel



Figure 7.23: Panel Stone Finish 1



Figure 7.24: Panel Stone Finish 2



Chapter 8: Ferraro Choi Case Studies

Introduction

Ferraro Choi and Associates is a very unique firm, not only in Hawaii, but also around the world. They are one of the few firms in the world that do work in Antarctica. As my design deals with cold weather conditions and exterior insulation systems, specialized cold weather work was extremely valuable, enabling me to refine the fiber cement panel design, as well as enabling me to determine a number of design strengths and weakness present in the fiber cement panels. In order to properly inform the design of the fiber cement panels, I examined 2 different panel systems that were designed by Ferraro Choi in Antarctica. Both are a form of structural insulated panel, one was on the coast of Antarctica and the other was at the geographic south pole. One of the panels is operating much more efficiently and the other has had major weakness due to poor construction quality.

In this portion of my research project, I examine these case studies, and find underlying design criteria that would be applicable in my own design, and then redesign the joints in fiber cement panels to incorporate elements as curtained from these case studies. In this chapter, we will begin with case studies on the two different panel designs, as well as a third case study on a new form of rebar free cement product. Then we will reexamine the joint designs of the fiber cement panels, and make design alterations as needed to the joint conditions.

Case Study: Crary Lab, McMurdo Station, Antarctica**Background:**

The Crary Lab is located, at the McMurdo Station on the coast of Antarctica. McMurdo Station is a science and research center operated by the United States National Science Foundation. The station is “located at 77 degrees 51 minutes S, 166 degrees 40 minutes E,[and] is the largest Antarctic station. McMurdo is built on the bare volcanic rock of Hut Point Peninsula on Ross Island, the solid ground farthest south that is accessible by ship.”¹ The station was created in December 1955 and Crary Lab was designed in 1987.² “Its 85 or so buildings range in size from a small radio shack to large, three-story structures. Repair facilities, dormitories, administrative buildings, a firehouse, power plant, water distillation plant, wharf, stores, clubs, warehouses, and the first class Crary Lab are linked by above-ground water, sewer, telephone, and power lines.”³

Being located in Antarctica, the station has very cold weather, “extremes have been as low as minus 50 degrees Centigrade (-58 ° F) and as high as plus 8 degrees Centigrade (46.4° F). Annual mean is minus 18 degrees Centigrade; monthly mean temperatures range from minus 3 degrees Centigrade in January to minus 28 degrees Centigrade in August.”⁴ Being such a cold location and having consistent cold weather year around makes the station an ideal case study for a research precedent. While the site in Volzhsky does not get anywhere near as cold in its most extreme, the average mean temperature is roughly the same as the average low temperature in Volzhsky. As the fiber cement panel design should be adaptable to all the climates in Russia, where some temperature differences are far more extreme, using this building as a major case study to inform the panel design has proven to be of great value.

1 National Science Foundation: Directorate for Geosciences, “McMurdo Station.”

2 National Science Foundation, “McMurdo Station.”

3 National Science Foundation, “McMurdo Station.”

4 National Science Foundation, “McMurdo Station.”

Figure 8.1: Crary Lab, McMurdo Station, Antarctica

<http://www.southpolestation.com/trivia/90s/crary.html>



Figure 8.2: Project Site Antarctica

Crary Lab Construction Documents, Ferraro Choi and Associates

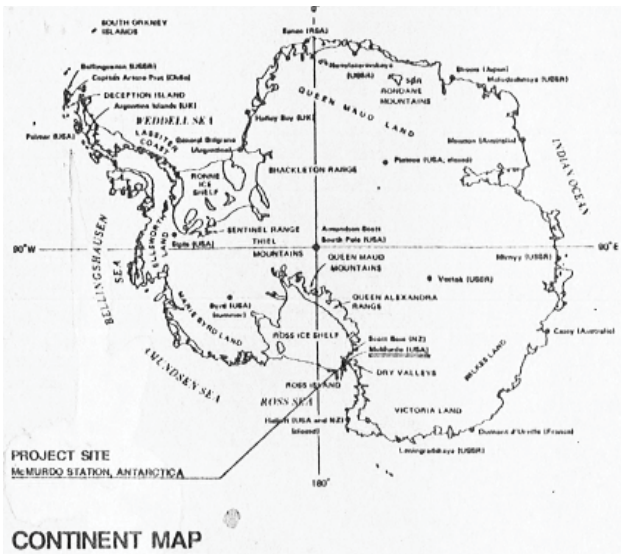
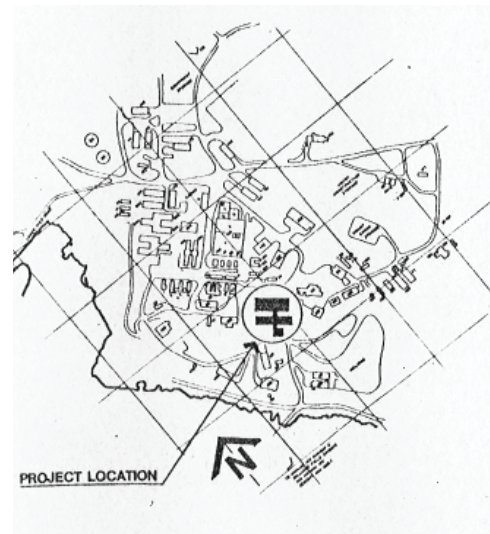


Figure 8.3: Project Site Antarctica

Crary Lab Construction Documents, Ferraro Choi and Associates



Crary Lab:

McMurdo Station was designed in 1987 by Joseph Ferraro, an architect in Hawaii. When discussing the design with Mr. Ferraro, he commented on one major construction flaw of the facility, which is that the contractors did not follow the detail which caused thermal inefficiencies in the exterior skin. Today, the Crary Lab Facility has major issues with its joint conditions. The main insulation typology is an insulated exterior panel as shown in the detail in Figure 8.5. However, I was informed by Mr. Ferraro that the panel joints were not constructed as detailed using common spray foam with a proper silicone that was specified.⁵ After reading the field report on the construction and reported issues/differences, two major areas stood out as causing thermal envelope inefficiency in the exterior skin.

The first issue was that the panel design called for a panel cap or cover plate to cover panel joint connections, which would create an overlap from one panel to the next thereby preventing the joint and end of the panel from being exposed to the elements.⁶ This is highlighted in Figure 8.7. Because the as-built joint does not have the overlap, the high wind is able to penetrate the façade and slowly degrade the field foam used on the interior between joints. The report stated that the probable reason for not having the correct corner panel is that they were expensive to manufacture; so budget issues hindered the performance of the insulation system. The other major issue is that the foam was installed poorly and in many cases, large gaps have begun to open between the joints. This in turn has caused the joint to degrade and led to significant worsening in the condition of the panel.⁷

The degradation of the joints has created major issues with air and moisture infiltration, especially during storms and other high wind events, which has caused snow to penetrate the façade inside the base floor cavity. Mr. Ferraro reported that the

⁵ Joseph Ferraro, Ferraro Choi and Associates Inc., Founding Principal

⁶ Roder, Adam G, Building Safety Inspector, "Review and Inspection of CSEC Building Envelope After 7/9/15 Storm Event," July 22, 2015

⁷ Roder, Adam G, "Review and Inspection of CSEC Building Envelope"

Figure 8.4: Crary Lab Floor Plan

Crary Lab Construction Documents, Ferraro Choi and Associates

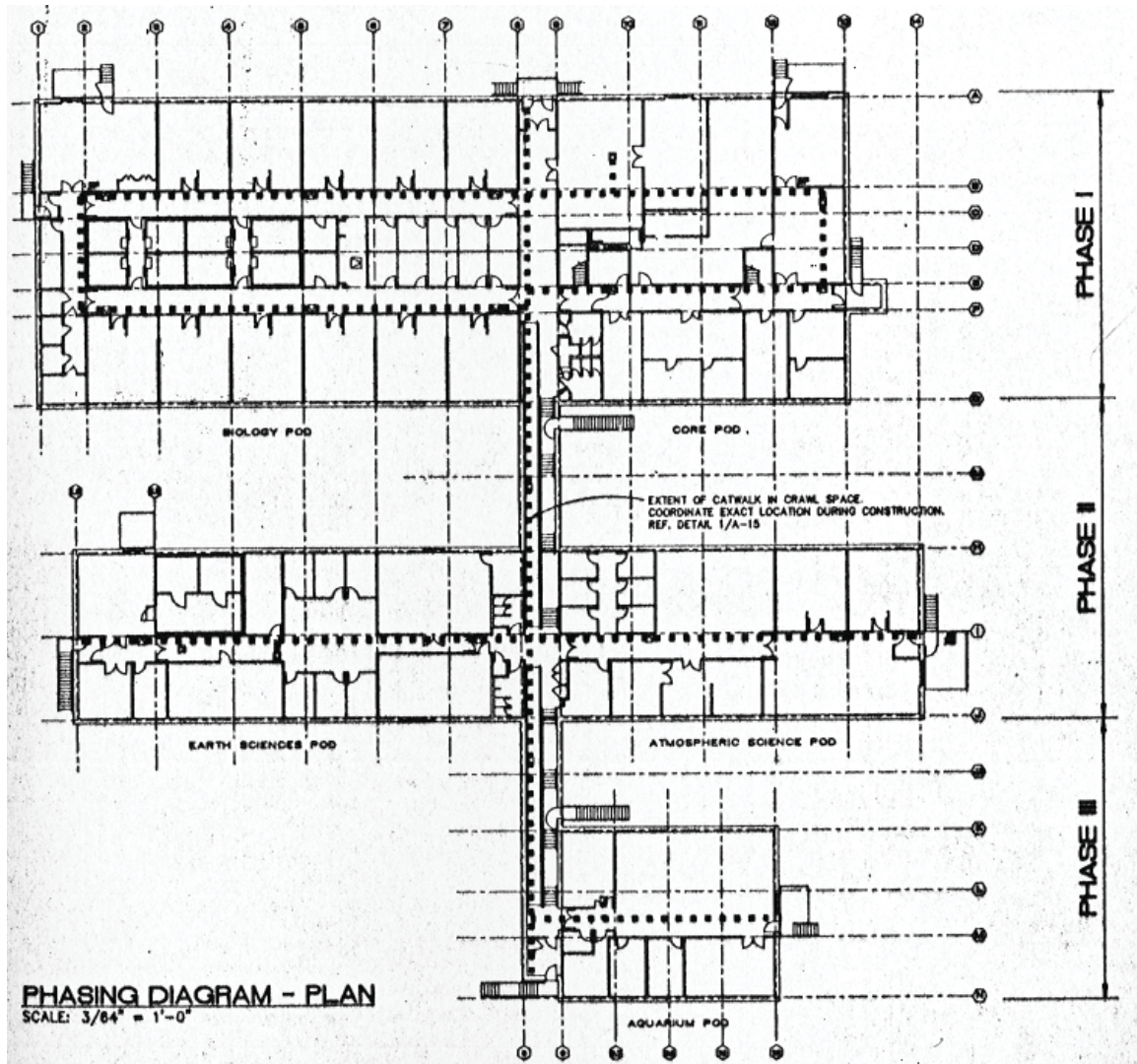
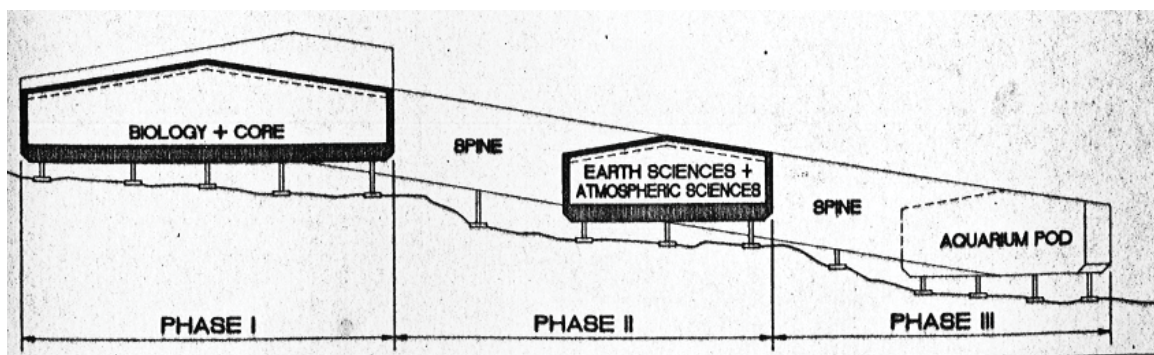


Figure 8.5: Crary Lab Basic Cross Section

Crary Lab Construction Documents, Ferraro Choi and Associates



exterior skin was designed to have an R-32 insulation rating. However due to the air leakage problems, the exterior skin is actually sustaining an R-15 rating which is far too low in this climate thereby causing excessive heating expenses and moisture problems. Due to these issues, Ferraro Choi and Associates has been contracted to redesign the skin which could either result in an alteration or retrofit of the skin, or a replacement of the skin, depending on cost factors.⁸

Because the facility was not built as designed, the current condition differs from the drawings. However, as the problems were caused by construction defects rather than the design, examination of the detail drawings at different joint conditions has still been very informative for the fiber cement panel joint design. In Figures 8.6-8.10, there are a series of joint, window and wall conditions. In each figure, an area is highlighted to denote a key feature that is beneficial to the fiber cement panel and joint design.

General Observations:

- Each panel is joined to the next panel at corner conditions using field foam between the panels and rib filler (with the top metal panel covering the joint on the exterior.)
- At attachment points, a vapor barrier tape is used on the screws that attach to the insulated panel.
- The connection between panels uses:
 - A ¼" x1 ½" foam tape sealant ;
 - Continuous vapor barrier tape at all joints on the interior face; and
 - Bead applied joint sealant on the interior of the joint connection of the panels at curved conditions as noted.

⁸ Joseph Ferraro, Ferraro Choi and Associates Inc., Founding Principal

Figure 8.6: Crary Lab Window Sill Detail
Crary Lab Construction Documents, Ferraro Choi and Associates

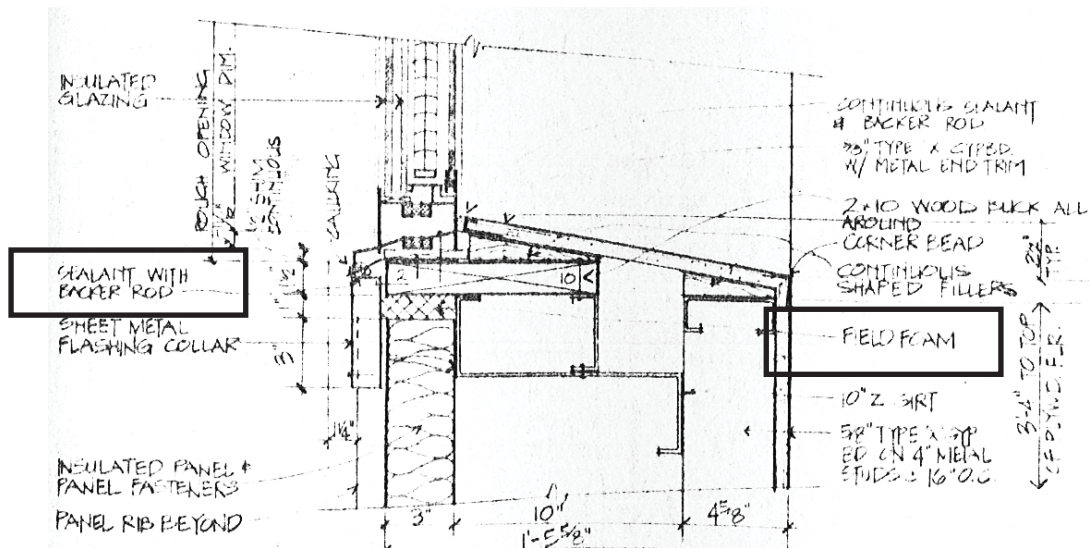


Figure 8.7: Crary Lab Detail at Base of 45° Soffit
Crary Lab Construction Documents, Ferraro Choi and Associates

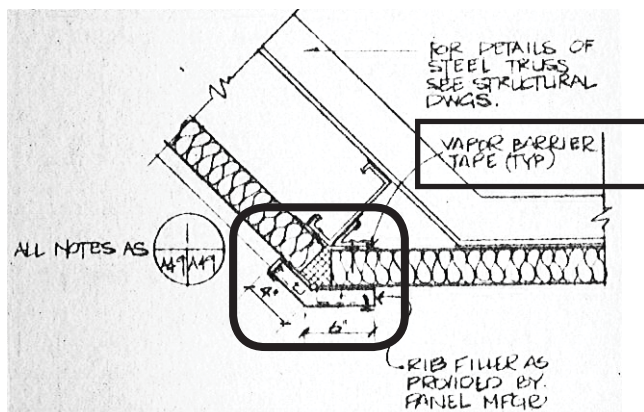
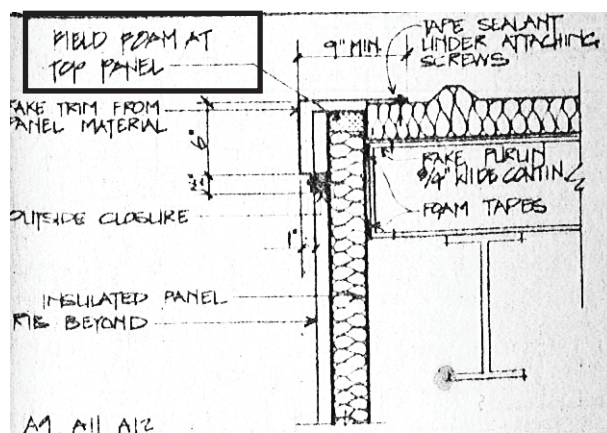


Figure 8.8: Crary Lab Detail at Base of 45° Soffit
Crary Lab Construction Documents, Ferraro Choi and Associates



Conclusions from Crary Lab:

Crary Lab is a perfect example of an extreme cold weather building condition to use as a case study for my own exterior panel design. After thorough examination of the wall and connection details of the exterior façade, a few main design principals have been determined. Most importantly, it is critical to create a continuous airtight insulation system. Due to deficiencies in construction resulting in a façade that was not made airtight, the R-value of the panels has been cut in half. This has dramatically reduced the ability of the exterior wall to keep the interior space at a comfortable temperature. Secondly, it is essential to have a continuous vapor barrier throughout the entire interior of the façade panel. Wherever punctures in the panel were made to fasten to the framing system, they were covered by a vapor barrier tape to minimize moisture penetration through the exterior of the façade. When dealing with such extreme temperatures between exterior and interior conditions, moisture will have a tendency to penetrate through any weak points which then degrades the façade and joint systems over time.

Case Study: South Pole Station, Antarctica**Background**

The South Pole Station is located at the exact southernmost point of the earth. It is in the middle of Antarctica and therefore, has far more extreme weather conditions than the weather at McMurdo Station. The South Pole Station was designed for the National Science Foundation for research in extreme Antarctic conditions. "Americans have occupied the geographic South Pole continuously since November 1956. The station stands at an elevation of 2,835 meters (9,306 feet) on Antarctica's nearly featureless ice sheet, which is about 2,700 meters (9,000 feet) thick at that location. The

Figure 8.9: Crary Lab Panel Clip Attachment
Crary Lab Construction Documents, Ferraro Choi and Associates

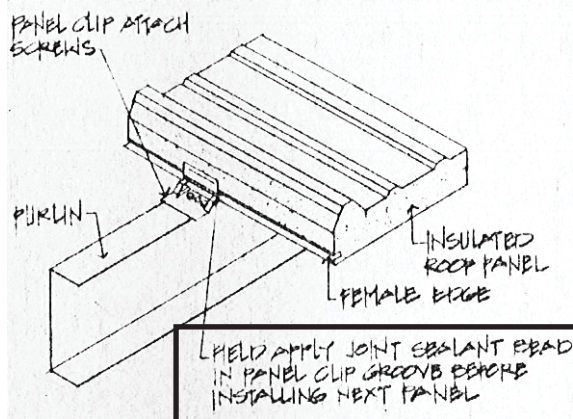
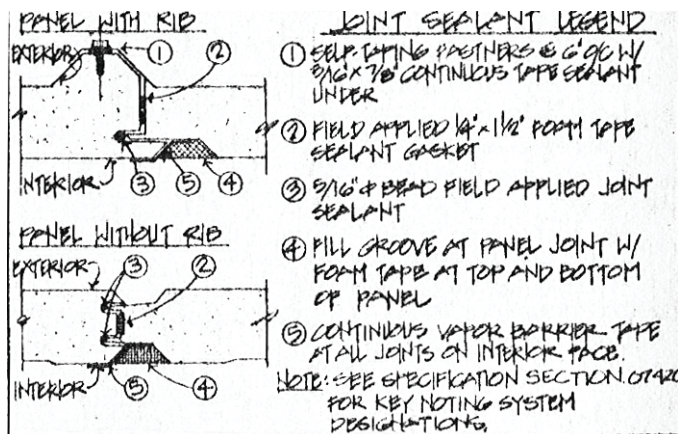


Figure 8.10: Crary Lab Insulated Panel Joint-Typical
Crary Lab Construction Documents, Ferraro Choi and Associates



station, which is 850 nautical miles south of McMurdo Station, is drifting with the ice sheet at about 10 meters (33 feet) each year.”⁹ The first station was built in 1957 and as interest in research at the South Pole grew, the need for a larger station increased.¹⁰ “In 1975, the central area of the station was rebuilt as a geodesic dome 50 meters wide and 16 meters high..., with 14- by 24-meter steel archways, covering modular buildings, fuel bladders, and equipment.”¹¹ As time continued, the need for a larger and more efficient design became apparent, and in “1997, a redevelopment plan to upgrade the station began. The new station, which was dedicated in 2008, is one connected, elevated facility. To accommodate changes in population from winter to summer, certain areas can be closed.”¹²

Current South Pole Station Design

The new South Pole Station was designed by Joe Ferraro of Ferraro Choi Associates along with a series of mechanical and structural engineers. There were a series of different design considerations that took place when this station was designed due to the fact that it sits on an ice sheet that is millions of years old and is miles above sea level. “As part of the elevated station, the existing arches were reused for fuel storage, cargo, and waste management. New arches accommodate the garage shops and power plant. The benefits of elevated structures include reduced snow drifting, increased building life, diminished environmental impact, enhanced safety, maximized solar energy use, and more cost-effective construction.”¹³

One of the most important design features of the station is its foundation and structure. The station sits on an ice sheet that continually gets thicker every year because of continuous compacting snow fall in a location that never thaws. “Snow accumulation is about 20 centimeters of snow (6-8 centimeters water equivalent) per

9 National Science Foundation: Directorate for Geosciences, “South Pole Station.”

10 National Science Foundation, “South Pole Station.”

11 National Science Foundation, “South Pole Station.”

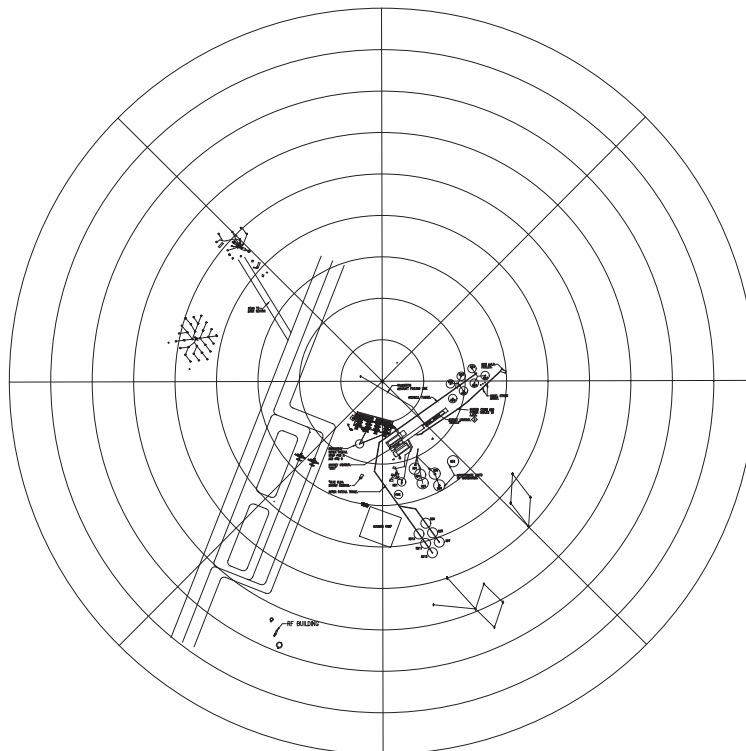
12 National Science Foundation, “South Pole Station.”

13 National Science Foundation, “South Pole Station.”

Figure 8.11: South Pole Station
<http://www.nsf.gov/geo/plr/support/southp.jsp>



Figure 8.12: South Pole Site Plan
South Pole Construction Documents, Ferraro Choi and Associates



year, with very low humidity.”¹⁴ In essence, this means the ground is continually rising so that the foundation structure consists of piles that are designed to jack up increasingly over time allowing the station to continually get taller as the ground level continues to rise. “Recorded temperature has varied between -13.6° C and -82.8° C. Annual mean is -49° C; monthly means vary from -28° C in December to -60° C in July. Average wind is 10.7 knots (12.3 miles per hour); peak gust recorded was 48 knots (55 miles per hour) in August 1989.”¹⁵ This is by far one of the most extreme climate conditions in the world and as such the station is a testament to human ingenuity and perseverance to occupy a location that is so extreme that someone without proper protection would literally die in minutes.

Because of the extreme climate conditions, it is essential to have a durable insulation system with the high thermal building efficiency necessary to survival at the South Pole. While the conditions in Russia are nowhere near as extreme as those at the south pole, important design principals were established in the design of this station that were transferable to fiber cement panel design. For instance, one of the most important features of the fiber cement panel is the ability for it to be adaptable to a variety of climate conditions in Russia, including Siberia which has weather that at time can be almost as extreme as those at the South Pole Station.

The exterior skin of the South Pole Station building is a combination of structurally insulated panels and a variety of joint conditions that together compose one continuous exterior skin system. The panels themselves are a metal panel with an EPS foam insulation interior. In Figure 8.16 shows the composition of the exterior wall panel skin. One clear difference between these panels and the panels at Crary Lab is the thickness, which is necessary to withstand the more extreme temperatures at the South Pole location. In addition, the roof panel is thicker than the wall panels in order to prevent the majority of the warmth of the interior heating from being lost through the

14 National Science Foundation, “South Pole Station.”

15 National Science Foundation, “South Pole Station.”

Figure 8.13: South Pole Floor Plan
South Pole Construction Documents, Ferraro Choi and Associates

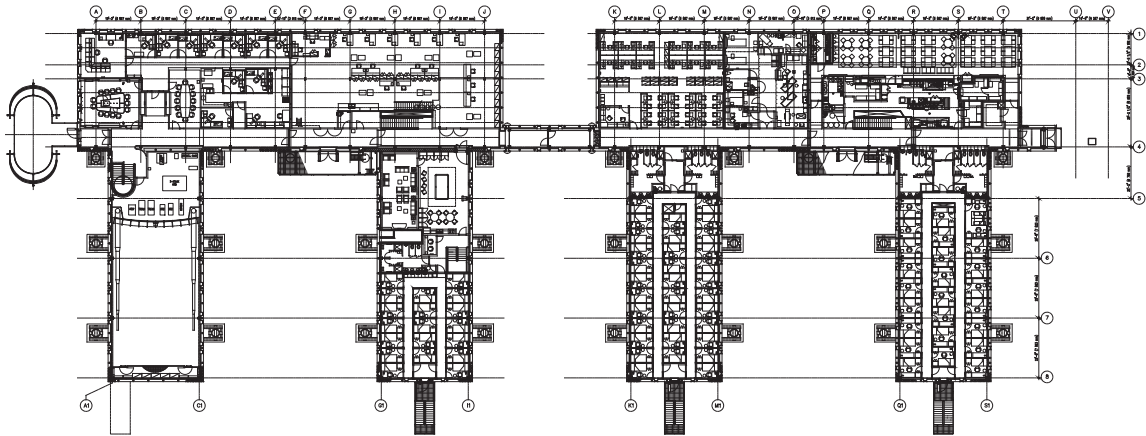


Figure 8.14: South Pole Elevation
South Pole Construction Documents, Ferraro Choi and Associates

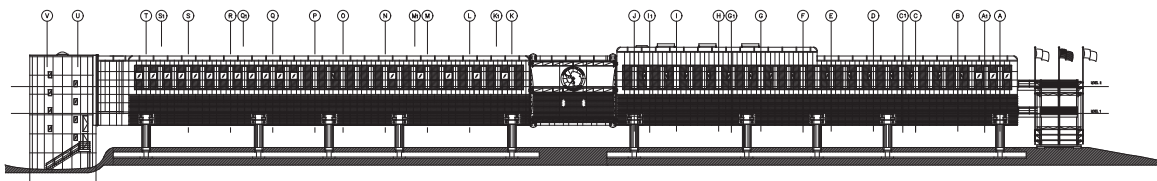
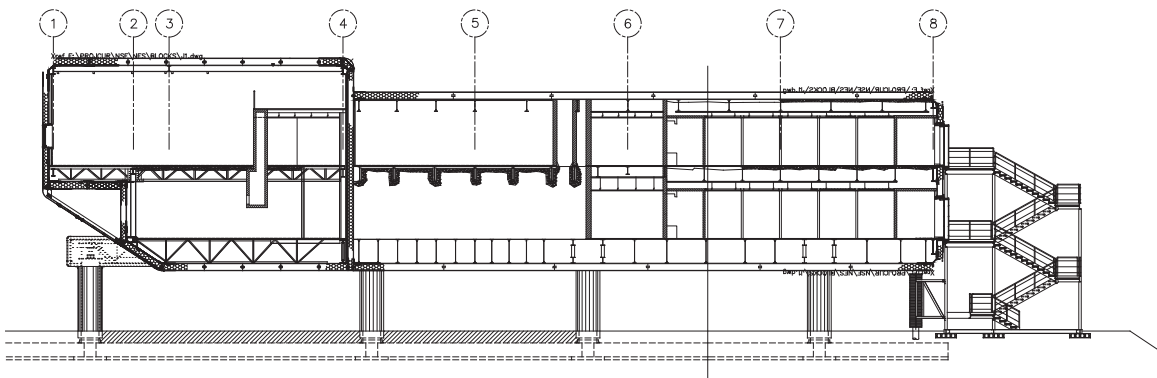


Figure 8.15: South Pole Basic Cross Section
South Pole Construction Documents, Ferraro Choi and Associates



roof.

As noted earlier, the exterior skin is a combination of panels and joints. The first major joint that occurs is a simple panel to panel butt joint where the two panels in the same plane are joined together. This is shown in Figure 8.17. The panels are joined together with spines that are made of wood particle board. There is an EPS spine on the interior and an OSB spine on both sides of the panel butt joint. Due to the structure and position of the spines opposite each other, it is possible to insert a screw on the interior of the panel to attach the metal skin to the wood spine thereby securing the two panels together. On the interior of the panel a field applied vapor barrier is added to insure a continuous vapor barrier on the interior at the connection points. On the exterior of the panel, the joints have a metal snap-on clip that covers the joint as shown in Figure 8.18. The overall goal of the panel is to ensure there are no air gaps or air infiltration at the panel to panel butt joint connection. Minimizing air and vapor infiltration improves the insulation value and the thermal efficiency of the exterior skin.

The other type of connection is at the joints where the panel changes direction along the exterior skin. This can be at the connections between a wall and roof or at the corners of the building where two walls are joined together. These connections are far more complicated and in the case of the South Pole Station building are angled to allow for a curved corner condition. A typical corner condition where the wall meets the roof is shown in Figure 8.19. Here in order to maintain insulation values, two 45° exterior panels are joined together with a small panel in between. They are joined in a manner similar to the butt condition with the EPS spine in the middle and wood blocking on the outside edges of the panel. In the corners, the wood blocking is thicker than it is in the wall panels. This has the effect of making the panel joints stronger. Finally, a new curved corner metal plate is placed over the corner joint in order to create a smooth exterior curved corner. Vapor barriers and field foam are used at the locations indicated in the Figure 8.19 in order to create an airtight joint condition.

Figure 8.16: South Pole Typical Insul. Building Panel
 South Pole Construction Documents, Ferraro Choi and Associates

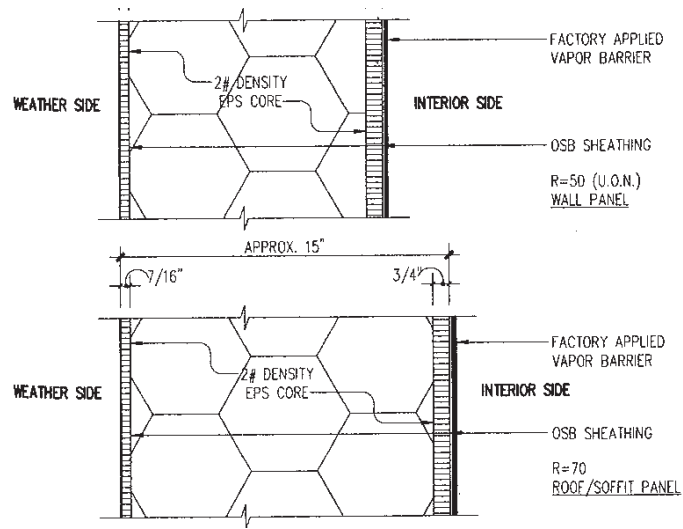


Figure 8.17: South Pole Insul. Bldg Panel-Typ. Butt Joint
 South Pole Construction Documents, Ferraro Choi and Associates

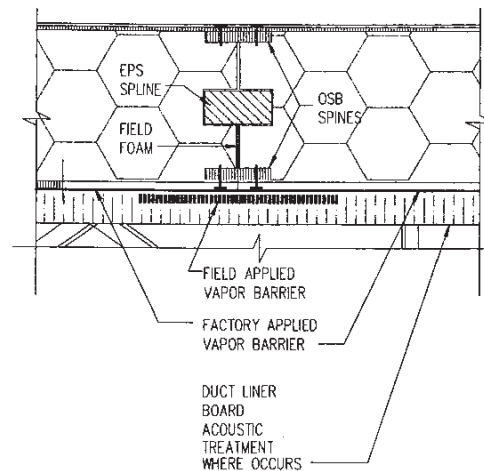
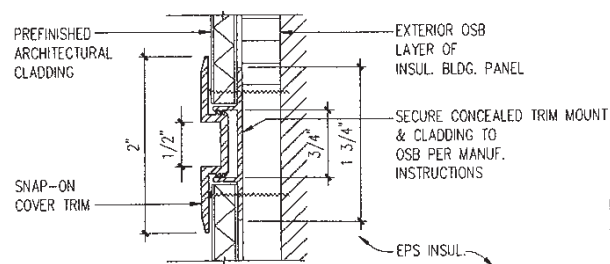


Figure 8.18: South Pole Cladding Trim- Typ. Butt Joint
 South Pole Construction Documents, Ferraro Choi and Associates



One of the most critical types of joint connections are those between the windows and wall panels. Because windows need to be transparent and are inherently thin to accomplish this, the windows at the South Pole Station, had to perform exceptionally well while still accomplishing the function of a window. The windows are exposed to extreme cold temperatures on the exterior and relatively warm temperatures on the interior. With interior temperatures between 18-21 ° C and exterior temperatures getting as low as -80° C, there is close to a 100 degree difference between the exterior of the window. Furthermore, as these windows are inserted into holes cut into the exterior insulation panels, their joint connections, sealants and vapor barriers must be airtight and capable of withstanding extreme temperatures.

A South Pole Station window detail is shown in Figure 8.20. The construction is surprisingly simple with the window sitting on a factory installed wood (nailer) or block with exterior aluminum trim. The window itself sits on a field installed compressible insulating weather seal that surrounds then entire perimeter of the window. This provides the airtight seal as well as improved insulation at the window to wall connection. On the interior a basic aluminum sill, head, and jambs is installed to fill the gap between the window and the end of the interior GYP board wall. The most robust portion of the design is the window itself, which is essentially a quadruple pane window. It consists of a typical triple pane window with an extra 1/8" vinyl sheet on the interior for added membrane protection.

General Observations

- The South Pole Station detail notes reflected in figure 8.21 include:
 - The vapor barrier strips overlapped each side of every panel joint by a minimum of 4 inches in order to ensure complete membrane protection.
 - The vapor barrier is either field applied sticky tape style or factory installed on the panel.

Figure 8.19: South Pole Insul. Bldg Panel - Roof Radius
 South Pole Construction Documents, Ferraro Choi and Associates

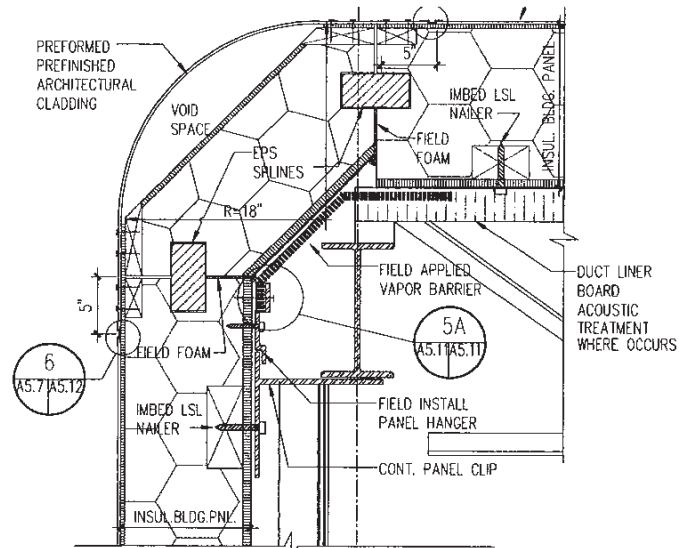
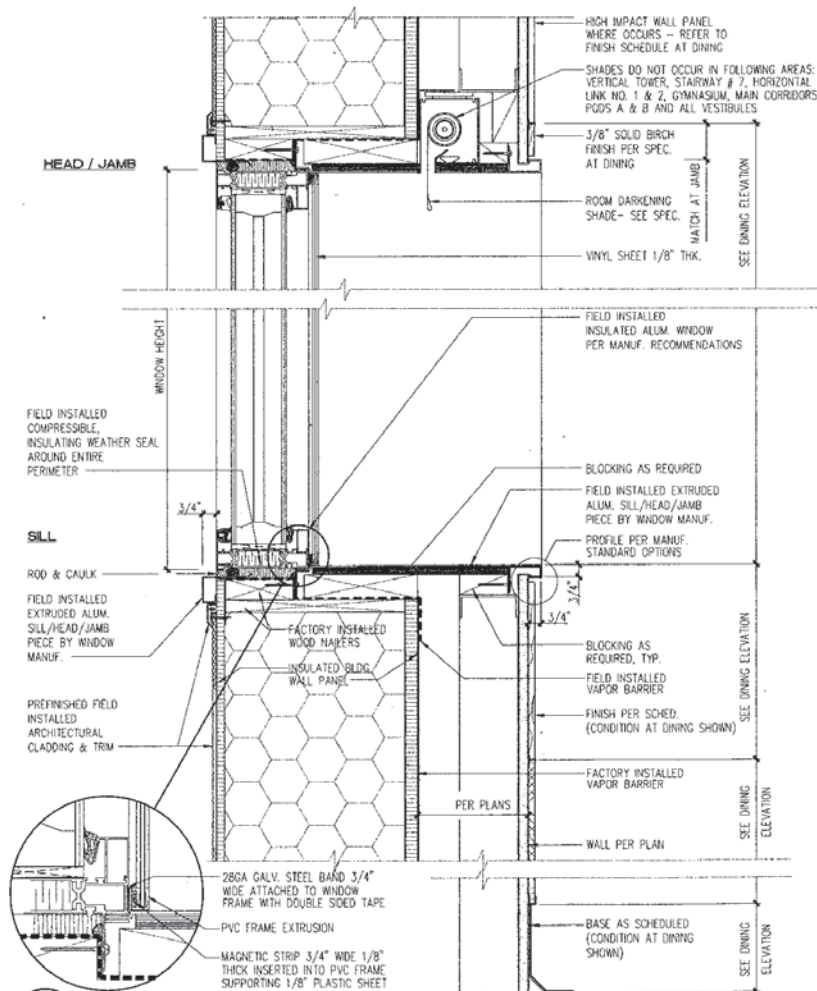


Figure 8.20: South Pole Window Section Detail
 South Pole Construction Documents, Ferraro Choi and Associates



- Field foam was applied to all joints prior to vapor barrier installation
- Field foam is applied at all joint locations. However, the field foam in these joints is much thinner than in Crary lab, and the majority of the insulation is built into the panel.
- Cladding joint clips are installed on exterior to protect the connection locations and ensure the exterior is airtight.
- Panels connect with an EPS foam interior spine and some form of wood blocking at the exterior which is very different from Crary.

Conclusions from South Pole Station

Due to its location, South Pole Station represents the most extreme insulation system requirement in the world. While the location's weather is far different than the site location is in Russia, important fundamental design principles were found that helped to insure a more effective exterior insulation system. These systems influenced my panel and joint design to ensure a more thermally effective final product. The way in which the South Pole Station panels connect together and the need for a consistent vapor barrier on the interior have given great insight into the connections of the fiber cement panels.

The only issue that has occurred with South Pole Station and its operation has been with the initial construction. Originally when the station was constructed, the contractors did not install the interior vapor barrier that is shown on the corner detail in Figure 8.19 shown earlier. They decided not to install a vapor barrier at that connection point, and after the station was completed, there was noticeable icing occurring at the corners of the station walls. The contractors then admitted that they did not install the vapor barrier and they had to rip out all of the interior walls at the corner locations and remove the beam that the corner rested upon in order to install the vapor barrier

Figure 8.21: South Pole Detail Notes:
South Pole Construction Documents, Ferraro Choi and Associates

INSULATED BLDG. PANEL GENERAL NOTES:

1. INSULATED PANEL LENGTH, WIDTH, JOINERY DETAILS AND CONFIGURATION SHALL BE AS INDICATED ON THE DRAWINGS OR AS OTHERWISE PROPOSED BY PANEL MANUFACTURER TO EQUALLY MEET OR EXCEED THE DESIGN SHOWN. DESIGN INCLUDES RELATIONSHIPS TO EXTERIOR DOORS AND WINDOWS, AND PREFINISHED CLADDING.
2. EXPANDED POLYSTYRENE CORE PANELS SHALL BE OF THICKNESS REQUIRED TO MEET SPECIFIED R – VALUE (EXCLUSIVE OF OSB OVERLAYMENT).
3. DRAWINGS INDICATE GENERAL PROVISIONS FOR SECUREMENT OF PANEL SYSTEM TO BUILDING FRAME. PANEL MANUFACTURER'S SHOP DRAWING SHALL INDICATE SIZE, TYPE, AND FREQUENCY OF ALL NECESSARY PANEL SECUREMENT SYSTEM COMPONENTS.
4. FIELD APPLY SELF ADHERING VAPOR BARRIER CLOSURE STRIPS OVER ALL INSULATED PANEL JOINTS, WHETHER THE JOINTS ARE EXPOSED OR CONCEALED, TO YIELD A COMPREHENSIVE, MONOLITHIC MEMBRANE. VAPOR BARRIER STRIPS SHALL OVERLAP EACH SIDE OF EVERY PANEL JOINT BY A MINIMUM OF 4".
5. PRIOR TO FIELD APPLYING VAPOR BARRIER TO INSULATED PANEL JOINTS, FIELD FOAM ALL EXPOSED GAPS BETWEEN PANELS.
6. IN ALL BELOW FLOOR CRAWL SPACES AND ABOVE CEILING PLENUM SPACES, FIELD APPLY 1/4" GYPSUM BOARD FINISH TO ALL EXPOSED COMBUSTIBLE SURFACES WITH A COMBINATION OF SELF TAPPING DRYWALL SCREWS AND PANEL ADHESIVE. EXPOSED VAPOR BARRIER SHALL BE CONSIDERED COMBUSTIBLE. SEE BLDG. SECTIONS FOR INDICATION OF AREAS TO RECEIVE FINISH.

properly.¹⁶ It was a major ordeal and it illustrates how important a vapor barrier can be when dealing with extreme weather conditions and an interior space that is humidified for comfort.

Fiber Cement Panel Design Changes

Now that a more thorough understanding of a successful panel design in extreme weather conditions has been examined, it is necessary to re-examine the fiber cement panel joint designs. The major principals that must be applied to the fiber cement panel are: the need for a proper airtight seal and a vapor barrier between panel connections. Furthermore, the window condition must be redesigned.

The window condition is the only location where the panels penetrate to the interior of the façade and as such, most of the vapor barrier and insulation improvements must be made at this location. Since the windows represent a rather large portion of the façade exterior weakness, improvements here could greatly affect the overall R-value of the panels on the exterior façade. The vapor barrier of the existing

¹⁶ Joseph Ferraro, Ferraro Choi and Associates Inc., Founding Principal

Figure 8.22: Window Sill Design Detail

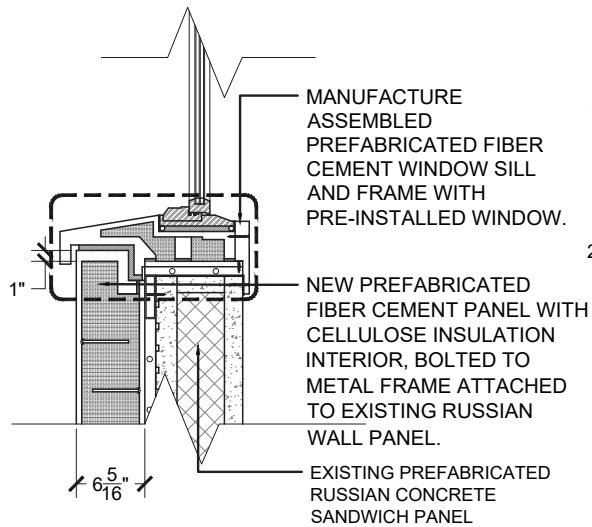


Figure 8.23: Panel to Panel Detail

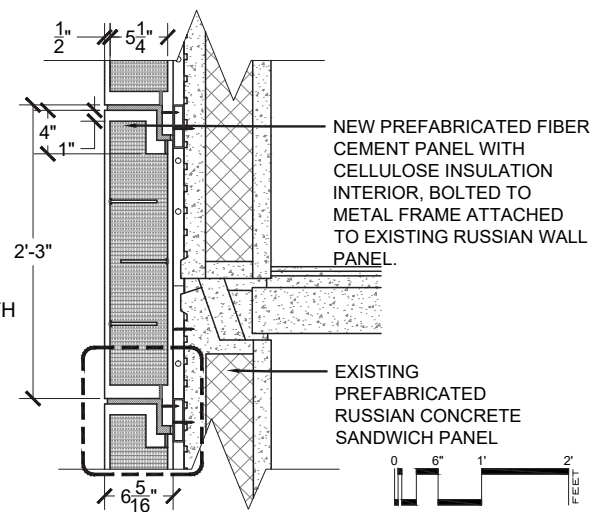


Figure 8.24: Panel to Panel Call-Out Detail

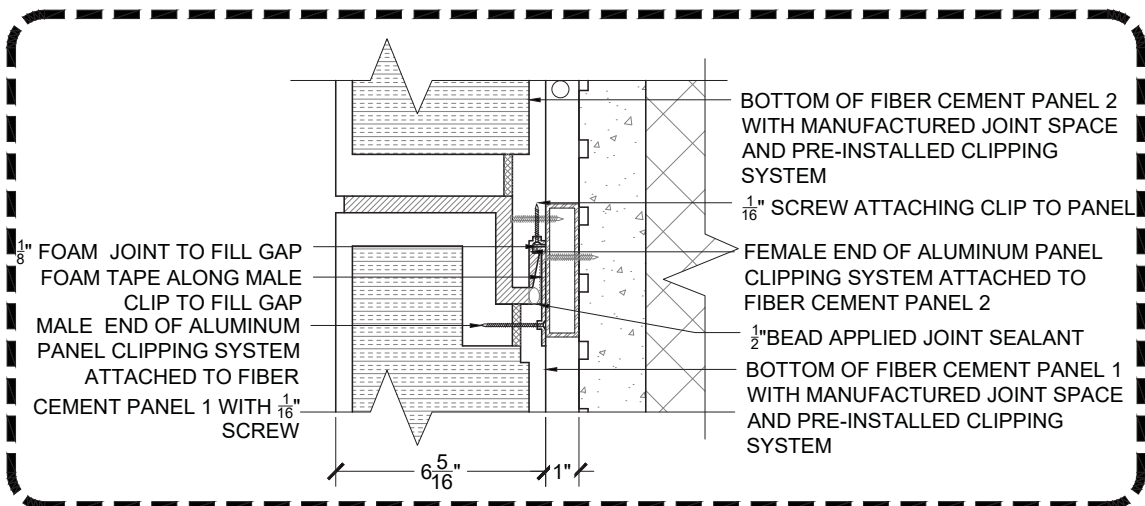


Figure 8.25: Window Sill Design Call-Out Detail

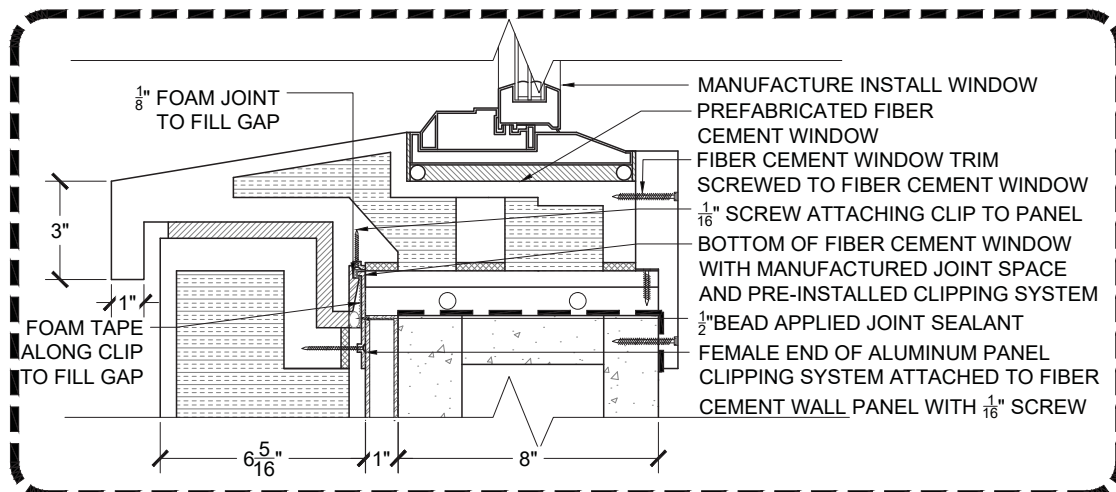


Table 8.1: Thermal Gradient Chart

R-Value		Temp Difference	
		68	Interior Temp
5	$(5/28) = .18 \times 86 = 15.48$	52.52	
1	$(1/28) = .036 \times 86 = 3.096$	49.424	
0.25	$(.025/28) = .009 \times 86 = .77$	48.65	
21.5	$(21.8/28) = .778 \times 86 = 66.9$	-18.25	
0.25	$(.025/28) = .009 \times 86 = .77$	-19	Exterior Temp

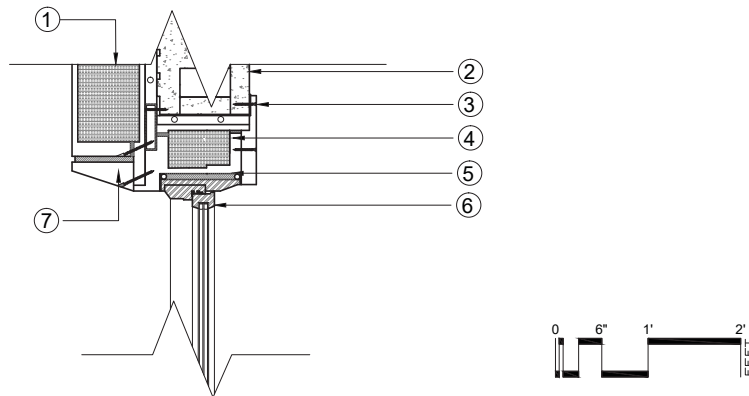
Stein, Benjamin, John S Reynolds, Walter T. Grondzik, Alison G. Kwok. Mechanical and Electrical Equipment for Buildings. Tenth Addition. Chapter 7, Page 193.

wall will be sufficient for the interior spaces however, as the new insulation will move the dew point location to within the new fiber cement panels certain vapor controls must be implemented.

Table 8.1 shows a thermal gradient calculation for the most extreme temperature condition of the wall system. Highlighted in yellow is the interior insulation section of the panel. Because this area represents such a massive portion of the new insulation value, the dew point will occur within the wall panel. In order to accommodate this design condition the panels themselves will be factory sealed together and have a fluid applied coating on the interior cavity to prevent any moisture from penetrating the panel. This will effectively mitigate the dew point problem.

Figures 8.22 and 8.23 show the existing current joint conditions between panels and at the window location. An improved airtight sealant is needed between panels, one major yet simple design change is the need to add a bead of insulation in the panel joint which will then bond the two panels together at the urethane connection. The panels are then bolted together, creating a vacuum press on the urethane foam pad between panels which should provide the necessary airtight seal required. In addition to this, the lap joint that attaches the non-bolted side to the next panel will have a thin layer of foam tape on it to make an airtight seal at the base of that joint. These changes are shown in Figure 8.24.

Figure 8.26: Window Head Detail



1. NEW PREFABRICATED FIBER CEMENT PANEL WITH CELLULOSE INSULATION
2. EXISTING RUSSIAN WALL PANEL
3. INTERIOR PREFABRICATED FIBER CEMENT WINDOW TRIM FASTENED TO NEW PREFABRICATED FIBER CEMENT INSULATED WINDOW PANEL FRAME WITH $\frac{1}{4}$ " SCREWS
4. MANUFACTURE ASSEMBLED PREFABRICATED FIBER CEMENT WINDOW SILL AND FRAME WITH PRE-INSTALLED WINDOW.
5. SILICONE SPACERS ON BED OF SILICONE
6. MANUFACTURE INSTALLED SLIDING INTERIOR WINDOW FRAME
7. NEW WINDOW HEAD END CAP SECURED TO PREFABRICATED WINDOW AFTER INSTALLATION WITH $\frac{1}{4}$ " SCREW IN PREDRILLED HOLE. FILL DRILL HOLE WITH SILICONE SEALANT MATCHING FIBER CEMENT COLOR

Figure 8.27: Left Window Jamb Plan Detail

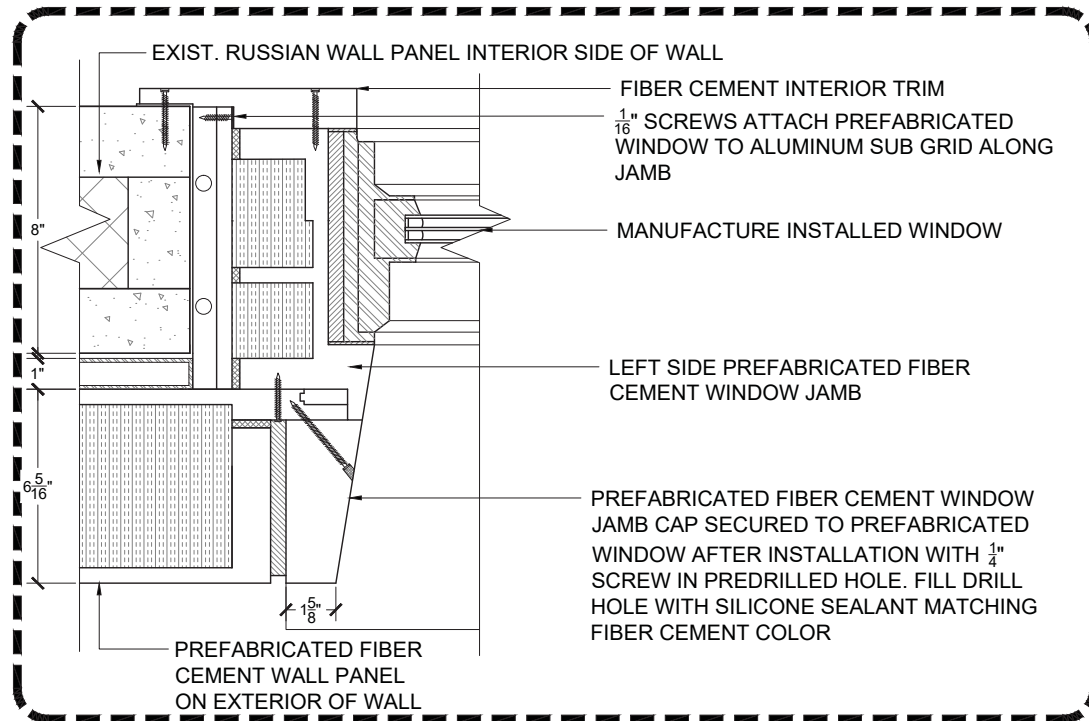
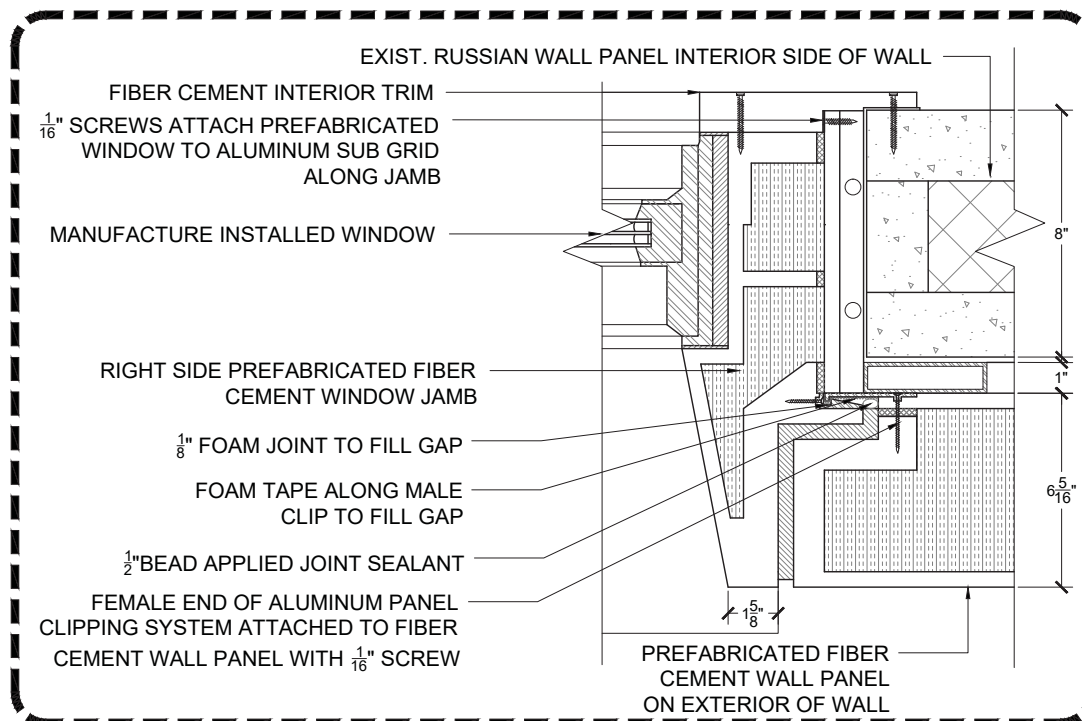
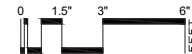


Figure 8.28: Right Window Jamb Plan Detail



The case studies also influenced the prefabricated window design. The original retrofit design of the windows failed to account for proper airtight seals and did not adequately address conditions that are present at each of jambs, head and sill locations. To address these deficiencies a separate window head, sill, and both the right and left jambs was created. The new window sill connection design is shown in the call-out in Figure 8.25. In this detail the connection between panels is shown, as well as, the addition of a drip edge at the bottom of the sill. A bead of insulation is added between the joint connections. The Head, Left Jamb, and Right Jamb joint conditions are shown in Figures 8.26, 8.27 and 8.28. Some of the complications with making a prefabricated window system to fit into the prefabricated panel system are that the head, jambs and sill all have very different design conditions.

These case studies also made it clear that it was necessary to address the design at the connection between the roof and the walls of the building. The original building has a partial wall or parapet at the very top of the building. At this location, the new wall panels will terminate at the top of the wall or parapet with a fiber cement parapet cap that is designed similarly to the window sill. This will create the most uniform look in the building façade. Determining the best way to insulate the roof was a different issue. To use the new panel design in this roof application, it would have to be altered to handle the different conditions present in a flat roof condition.

In designing the roof panel, It was desired to make the panel strong enough to handle minimum load requirements for a flat roof system. While Russia may not have the same code standards for a flat roof as does the United States, it was still important to make the panels as strong as possible in order to be able a to handle a minimum load of 40lbs/square foot. Fiber cement can achieve impressive strength to weight ratios, but short of making the fiber cement incredibly thick, it would be insufficient to hold the load requirements needed in a flat roof condition. Therefore it was necessary to find a design solution that would address the load demands.

Fiber Cement Strength Improvement Case Study

An important result of the research conducted at Ferraro Choi was the introduction to a new form of rebar-less concrete material being used in New York. This material is similar to fiber cement. However, instead of using fiber glass or wood pulp to strengthen the cement panels, they use very small twisted steel fibers that essentially increase the strength to weight ratio of the fiber cement allowing for an even stronger cement product. This product was created by Helix.

Helix micro rebar 5-25 “ is the only discontinuous concrete reinforcement product in the world that has an ISO certified design manual that can be followed to design vertical applications (such as walls) using it as the primary concrete reinforcement.”¹⁷ The material is certified to replace actual rebar in floor and wall applications. However, the micro rebar is not rated for specific location such as window heads and columns.¹⁸ The micro rebar has a structure similar to traditional rebar as it is a twisted steel rebar that is just a fraction of the size. The micro rebar is of a similar thickness as a paper clip. A full scale piece of micro rebar is show in Figure 8.29.

In order to specify Helix in construction, the engineer has to determine the required rebar design based on traditional methods, then using the worksheet from Helix’s” Rebar Calcs Table PDF document that can be downloaded from their website.¹⁹ Helix has calculation worksheets that are specified for floor, wall, and beam designs. The micro rebar can be used in a prefabricated or cast in place element. The micro rebar is mixed right in with the cement in the cement mixer. Helix gives specific recommendations on how to mix affectively with several different mixing sources, and then they specify how much slump is ideal for the concrete to have the correct strength ratios.²⁰ Slump is a technical term that determines the malleability of concrete when it is being poured. It refers to the amount of bulge that occurs in wet concrete or cement

17 Helix TM, “Helix Micro Rebar,” *Technical*, Copy Right 2012, Polytorx, LLC

18 Helix TM, “Helix Micro Rebar” *IAPMO Uniform ES*. December 2013, 11

19 Helix TM, “Helix Micro Rebar” *IAPMO Uniform ES*. December 2013, 11

20 Helix TM, “Helix Micro Rebar” *IAPMO Uniform ES*. December 2013, 11

Figure 8.29: Helix Micro Rebar
Helix.com

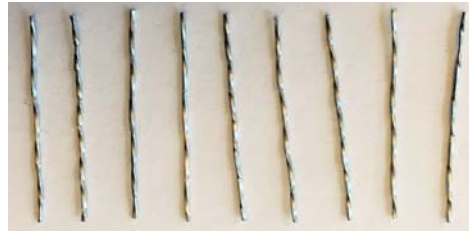


Figure 8.30: Helix Top 10 Reasons
Helix.com

Top 10 Reasons: To Design with Helix Micro Rebar vs. Rebar/Mesh

1. **Helix Eliminates Placing Errors.**

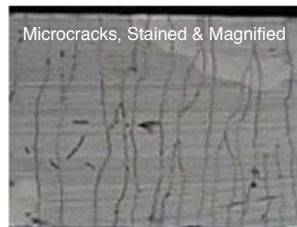
Helix avoids placement errors since it is distributed throughout the concrete matrix. Traditional reinforcement's effective strength is decreased by up to 50% when misplaced. Placing chairs, and their potential for weakening the concrete, are also eliminated.

2. **Helix Provides a 40% Plus Stronger Concrete Section.**

Helix is a multidirectional reinforcement that increases shear strength and decreases the need for stirrups.

3. **Helix Allows the Concrete to Absorb 200% Plus More Energy.**

Helix adds durability and impact resistance to the concrete which is excellent for heavy loads and seismic events.



4. **Helix has Excellent Crack Control Properties.**

Helix is designed to keep cracks tight and short when they develop allowing the concrete to micro crack but not develop a large, dominate crack.

5. **Helix is a Safer, Discontinuous Reinforcement System.**

Helix does not allow for a complete failure of the system due to corrosion; unlike traditional reinforcement which is continuous and electrically connected.

6. **Helix Helps Increase Worksite Safety.**

Helix reduces injuries due to cuts (placing), strains (lifting) and tripping/falling (maneuvering through the grid) traditionally associated with rebar/mesh.

7. **Helix is Electroplated with Zinc.**

Helix has been tested in de-icing agents to resist rusting 3 times longer than standard rebar/mesh that has no coating.

8. **Helix Significantly Reduces Construction Time.**

Helix reduces construction time by eliminating laying, tying, and inspections and in most cases can eliminate the need for pumping and void development in highly congested steel locations.

9. **Helix Reduces Reinforcing Costs by at Least 20%.**

Helix eliminates the labor associated with rebar/mesh placement along with reduction of scrap, chairs and overlap splicing steel.

10. **Helix Can Help Achieve LEED Goals.**

Helix is made from 50% recycled steel and less overall weight of steel is used thus the emissions of trucks, forklifts and cranes are greatly reduced.



when placed in a cone shape about 12 inches high. A specialized slump measuring tool is used to determine the water ratio. A slump that is too great indicates the concrete is too wet and will have strength issues. A slump that is too small indicates concrete is too thick which means the water levels are insufficient which in turn indicates the concrete will be very difficult to work with.

To finish the concrete completely, Helix specifies a 4 step process to ensure that the micro rebar settles below the surface of the concrete. Step one specifies the use of a vibrating screed to get the rebar to settle below the surface; step 2 uses bull floating to eliminate ridges and fill in voids left by screeding; step 3 is power floating; and step 4 is troweling. Steps 3 and 4 are designed for a smooth surface. They can be changed to any finish desired in the manufacturing process.²¹

Helix Micro Rebar is an impressive innovation in concrete design. It is far superior to traditional reinforced concrete construction and is far stronger than fiber cement. Helix states that its overall cross section strength is around 40% or more multidirectional strength improvement as shown in their “Top 10 Reasons” to use their micro rebar in Figure 8.30. In essence, because the Helix micro rebar is placed at random in the concrete, they will strengthen in every direction. However, its cost is substantially higher than fiber cement, but 20% less expensive than traditional concrete and rebar.²² In essence, the product is great for replacing concrete and achieving very thin concrete elements. However, as the primary goal of this project is to provide less expensive retrofit options than those currently available in Russia, cost is a limiting factor.

Helix micro rebar will be ideal for the roof location of the design to increase surface strength of the panels. However, as the increased strength is not needed for the rest of the panels, the cheaper fiber cement option is a more cost effective material to use for the vertical wall panels. In addition, Helix Micro Rebar should create the footing

21 Helix TM, “Helix Micro Rebar,” *Helix Dosing Mix Design*, Copy Right 2012, Polytorex, LLC.

22 Helix TM, “Helix Top 10 Reasons: To Design With Helix Micro Rebar vs. Rebar/Mesh.” Copy Right 2012, Polytorex, LLC.

Figure 8.31: Roof Wall Section

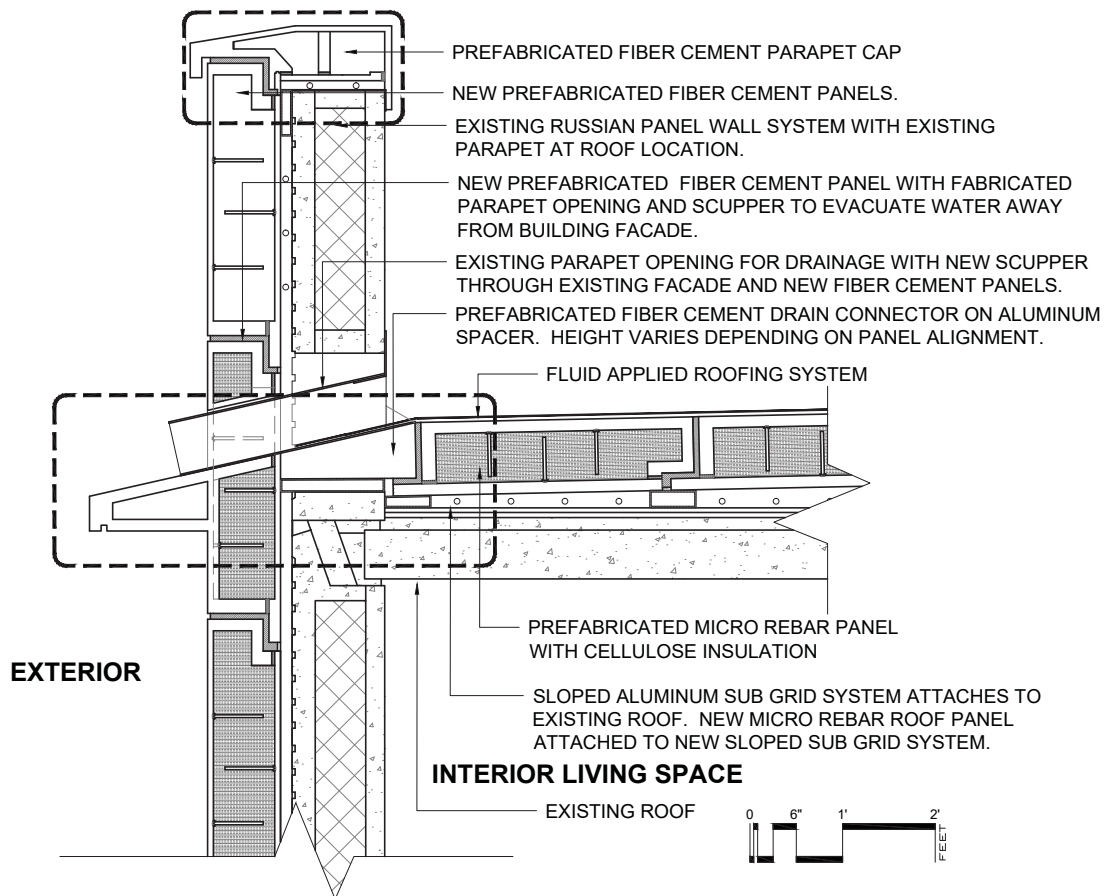


Figure 8.32: Roof Water Proofing Detail

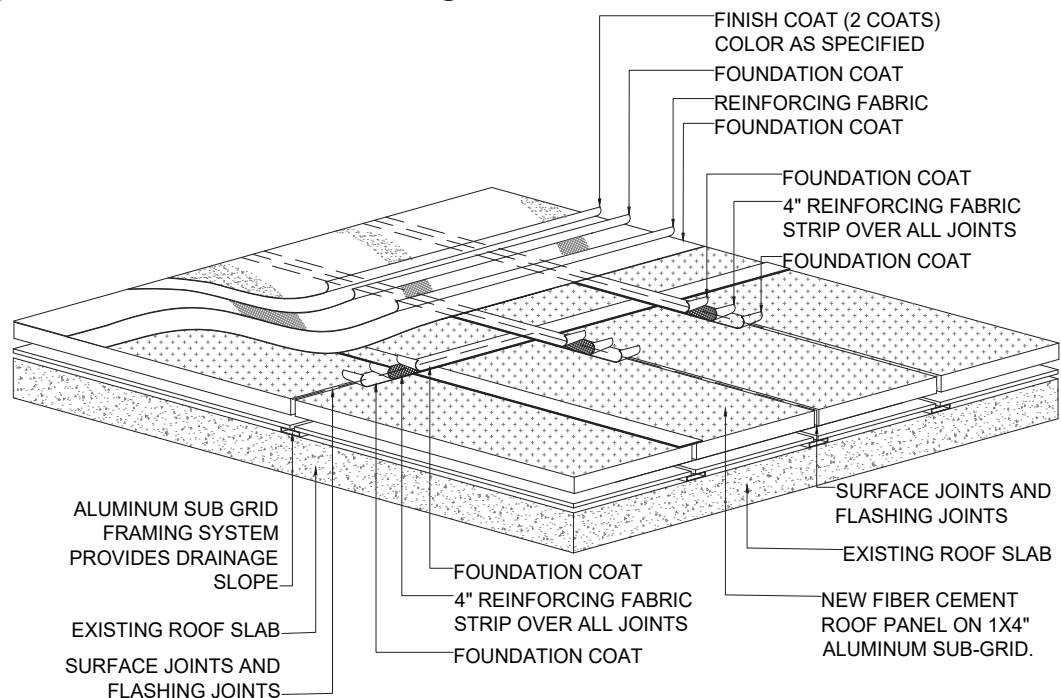


Figure 8.33: Roof Parapet Cap Call-Out Detail

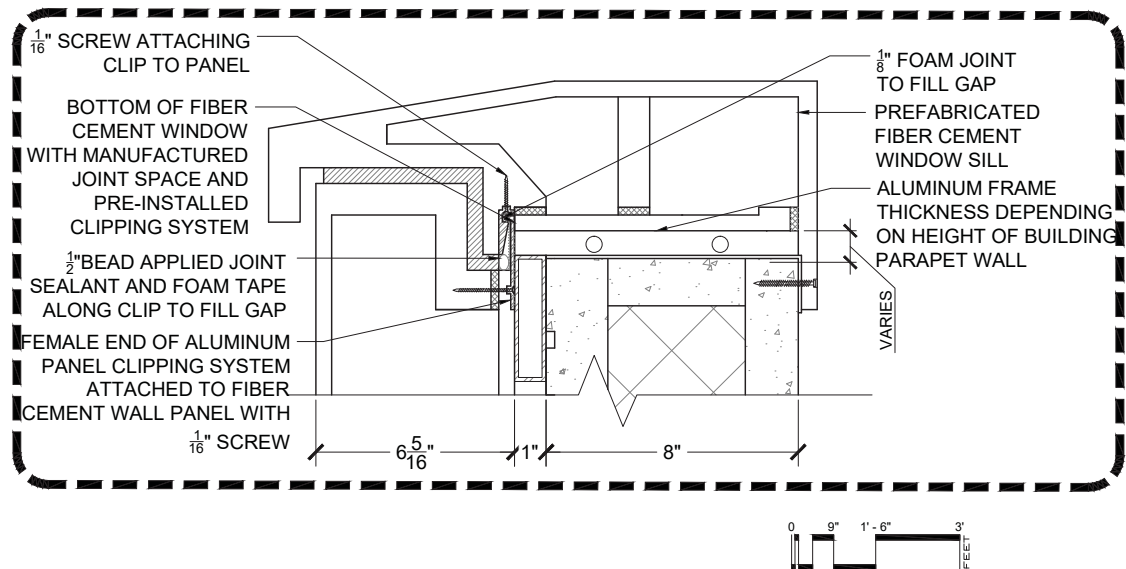
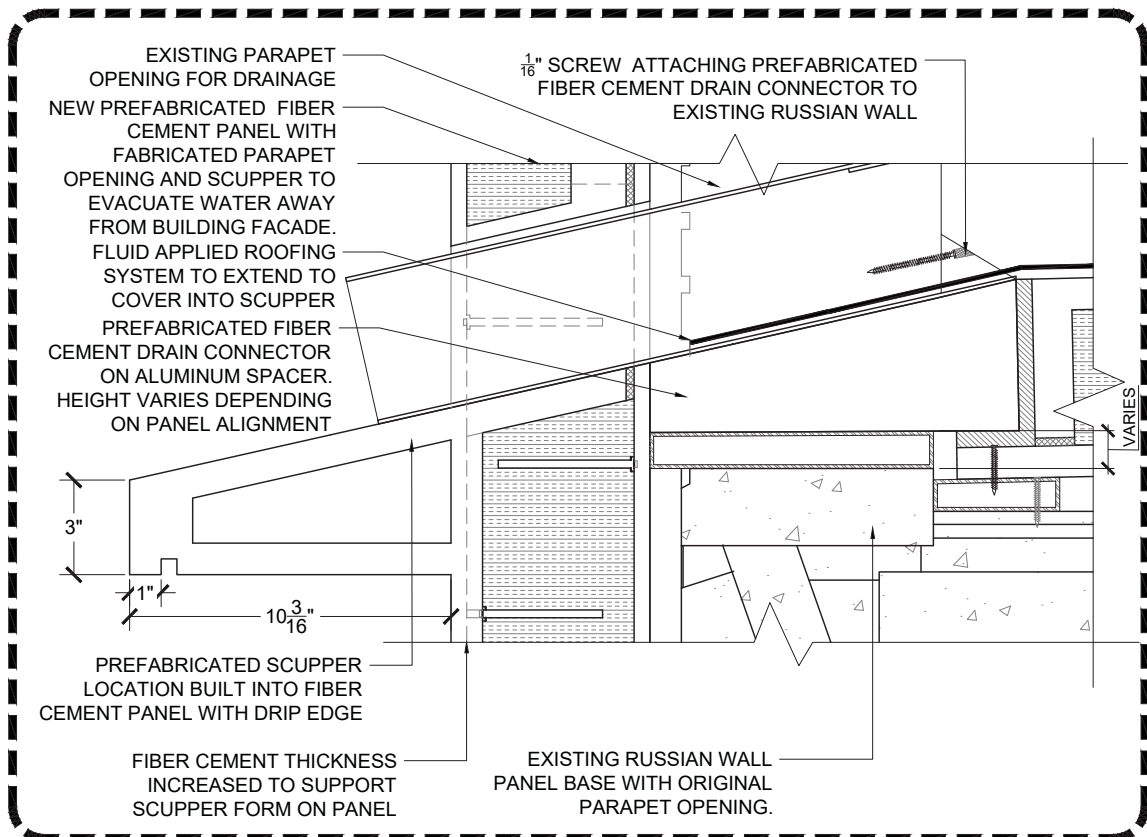


Figure 8.34: Roof Scupper Call-Out Detail



condition as the increased strength will be needed to help carry the load for the entire system.

Roof Panel Design

The roof panel design needed to have increased strength to handle the increase live and dead loads that will be acting upon them. In order to increase the strength, the thickness of the concrete inside the panel was doubled to 1 inch thick and the use of micro rebar was employed. The rest of the panel configuration remained the same. The same fastening system is as just in the horizontal application. In order to obtain the proper drainage slopes needed for a flat roof condition, the sub-grid placed under the panels increases in thickness from the edge to the center of the roof in order to create a sloped sub-grid system, which in turn will slope the panels based on the desired slope condition. In order to properly waterproof the panels, a typical fluid applied roofing system will be used to make the roof completely watertight. The roof panel wall section is shown in Figure 8.31, and an axon of the fluid applied roofing system is shown in Figure 8.32.

This new roofing system should have the same thermal envelope efficiency as the wall panels while at the same time handling the weight and the waterproofing complications of a flat roof condition. The parapet cap call-out detail and parapet scupper detail are shown in Figures 8.33 and 8.34. The original Russian wall parapet has an opening in the wall for drainage. For my panel application, a special designed panel with a space for a new scupper prefabricated into the construction allows for the water to be passed through the wall and evacuated off the roof. A new scupper is then installed in the roof that will keep a watertight seal through the roof parapet and off the building. A fluid applied roofing system will extend into the scupper, making the waterproofing stronger at these locations.

After designing the new roof panels, certain concerns have arisen in the

Figure 8.35: Roof Wall Section-Rigid Foam Board

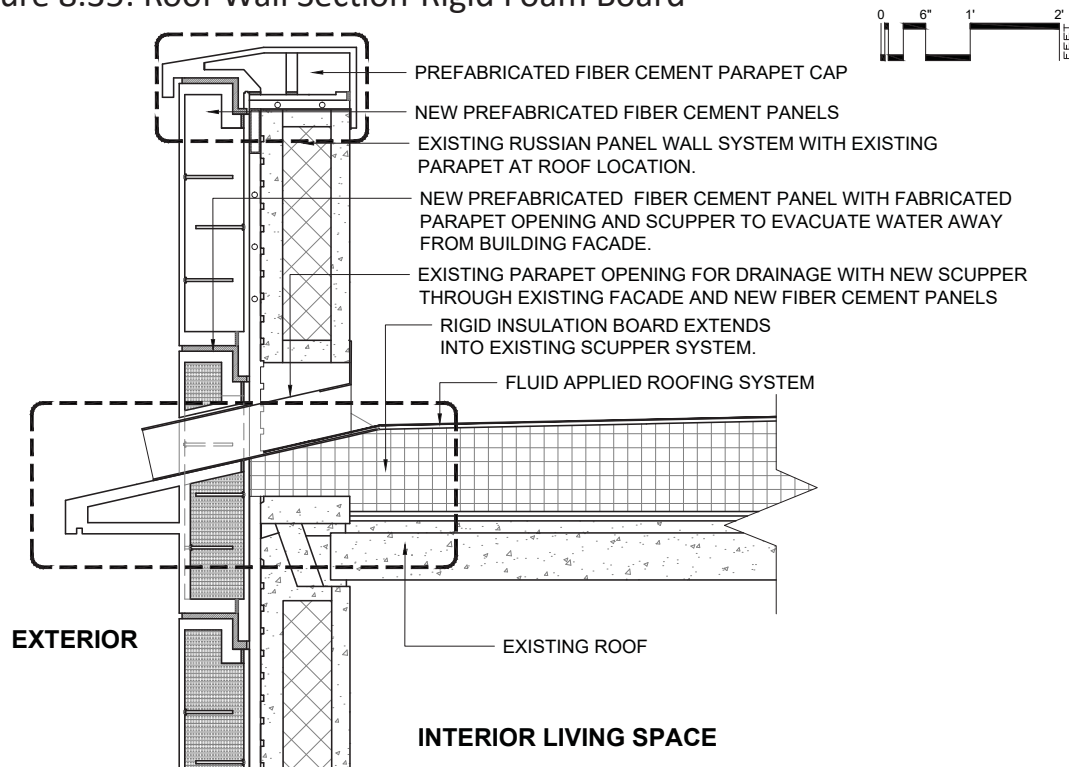


Figure 8.36: Scupper Call-Out Detail

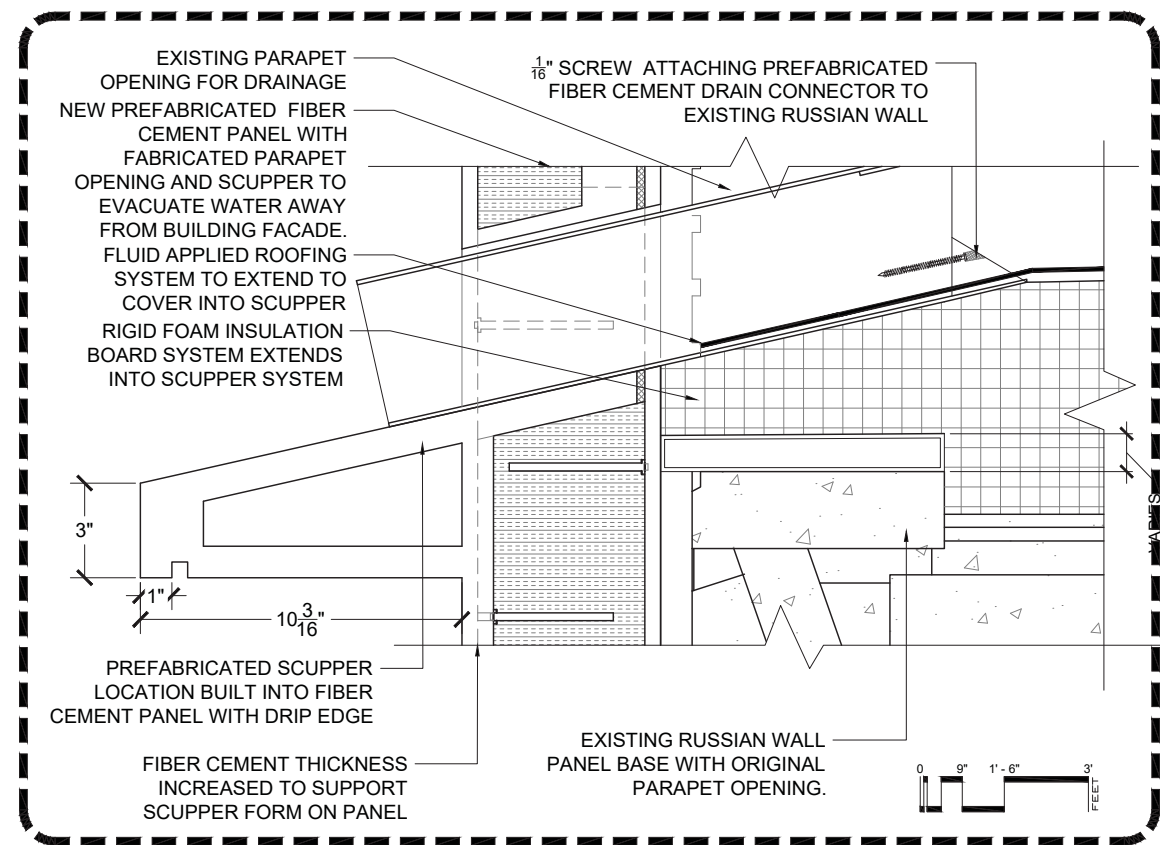
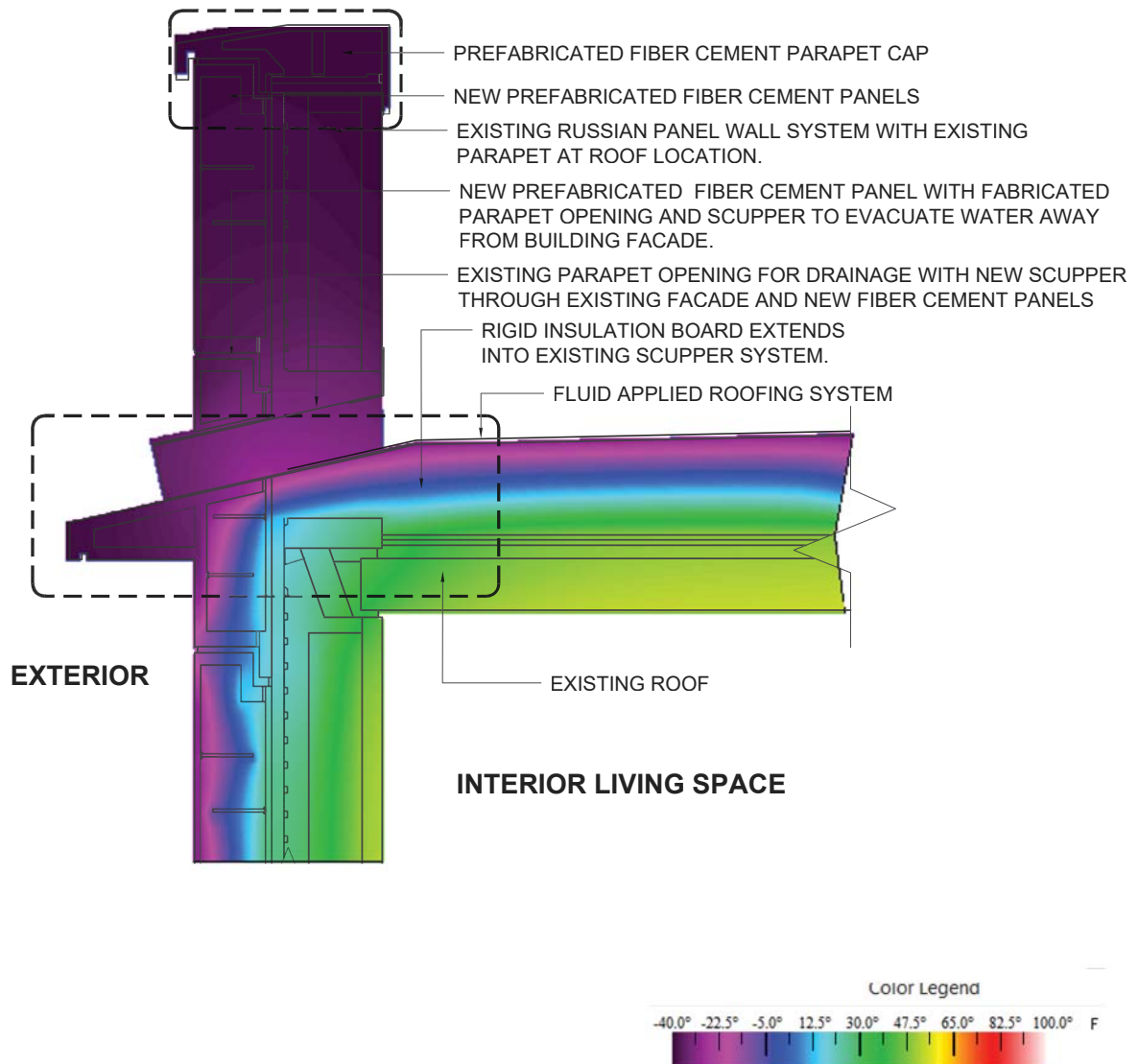


Figure 8.37: Panel Footing Wall Section Therm



implementation of them in the field. Due to the complicated nature of installing the panel system on the roof, as well as the increased weight of the panels for a thicker, denser version of fiber/micro rebar cement. The overall cost savings of using the panel in a roof application is minimized, and a more traditional roof insulation system is recommended.

Using a traditional roof insulation system that comprises of rigid foam insulation board with a fluid applied roofing system will be far easier to install and therefore reduce the cost of installation on the roof for the overall retrofit. This is because the sub grid system while designable to create the necessary drainage slopes for the panels, is more complicated to install than foam board. In addition, the new panels are heavy and increase the dead load on the roof far more than rigid foam board. Therefore it is recommended that the traditional method be employed in retrofitting these buildings in Russia. A section detail drawing of the traditional system being used in the retrofit is shown in Figures 8.35 and 8.36. These drawings show the use of rigid foam board panels that cover the roof and extend into the scupper system.

Finally, in order to test the new roof's design effectiveness, the design was tested in Therm 7.3 which is shown in Figure 8.37. Because the roof is using foam board insulation, there is no issues with the roof itself and thermal bridging, as well as, the transition/connection between the foam board and the new fiber cement wall panel. This was the weakest condition of the roof because the scupper locations make the foam board have to taper and thin for drainage through the scupper. However, as shown, the connection is sufficient to handle the cold and thermal loads.

Footing Design

Modifications to the footing design were relatively simple. The original building footing extends at varying distances into the ground. In order to properly support the entire structure, a Helix Micro Rebar prefabricated base will be created to rest on the

Figure 8.38: Panel Footing Wall Section

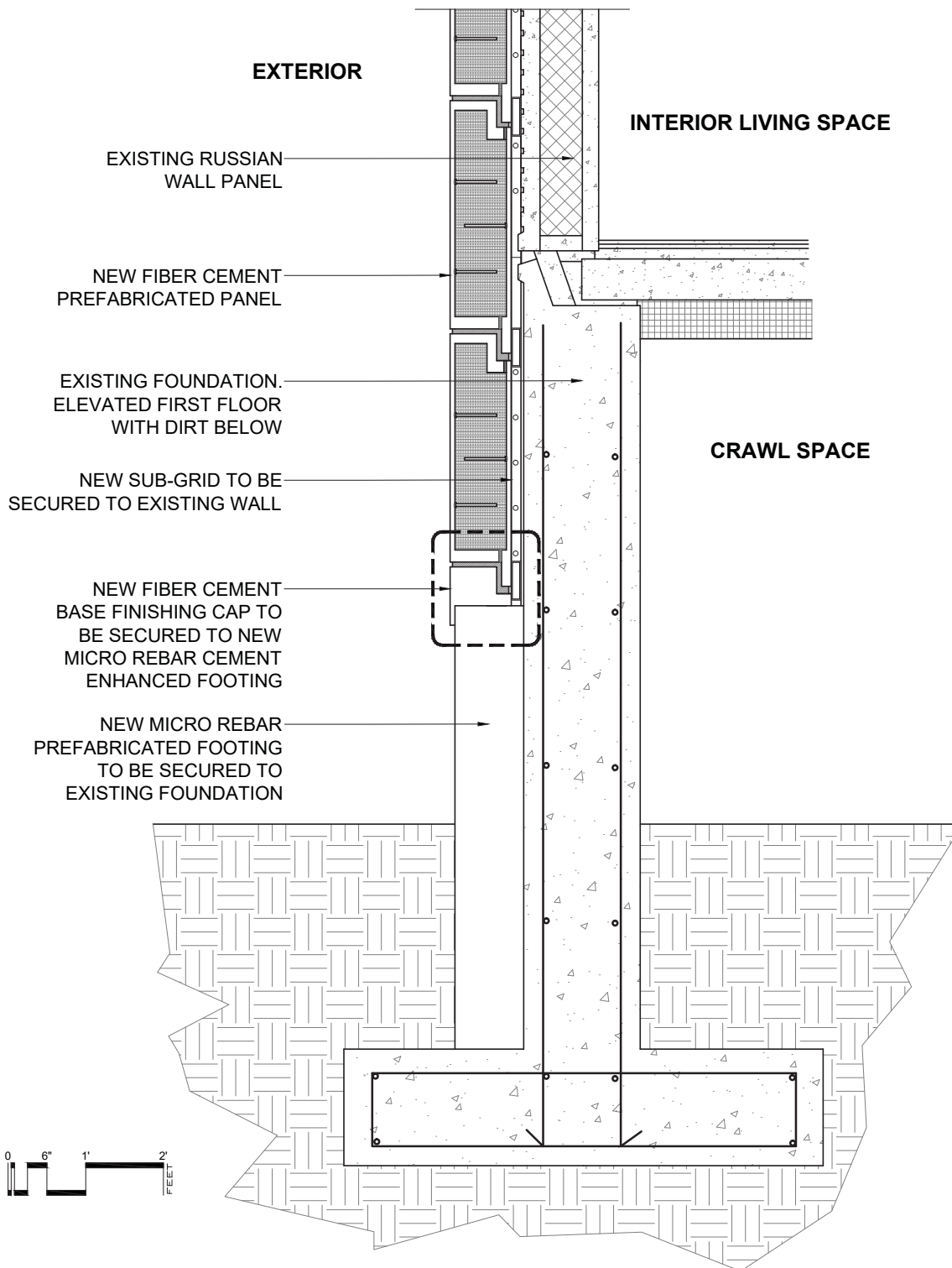


Figure 8.3:9 Panel Base Cap Detail

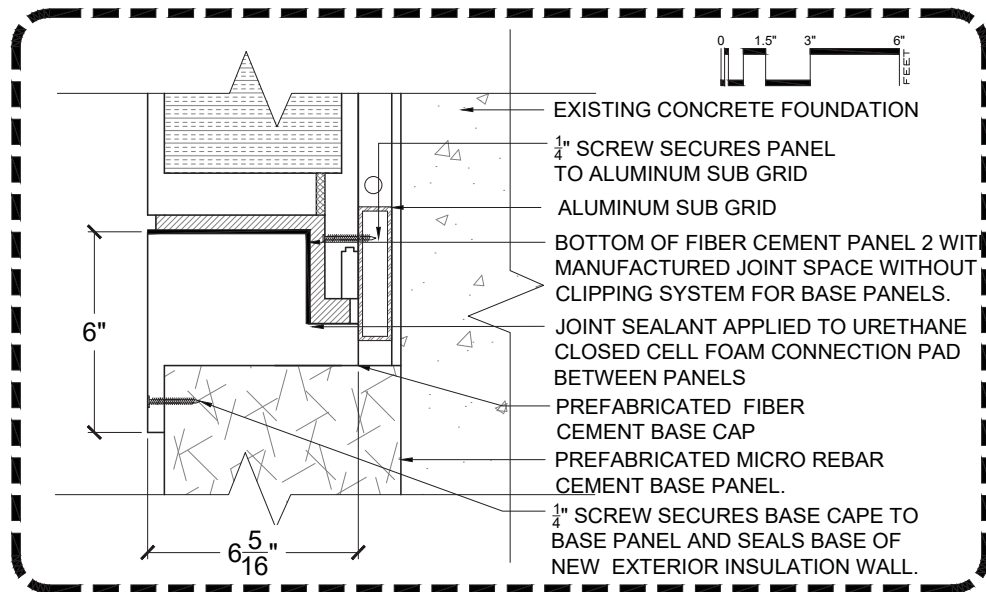
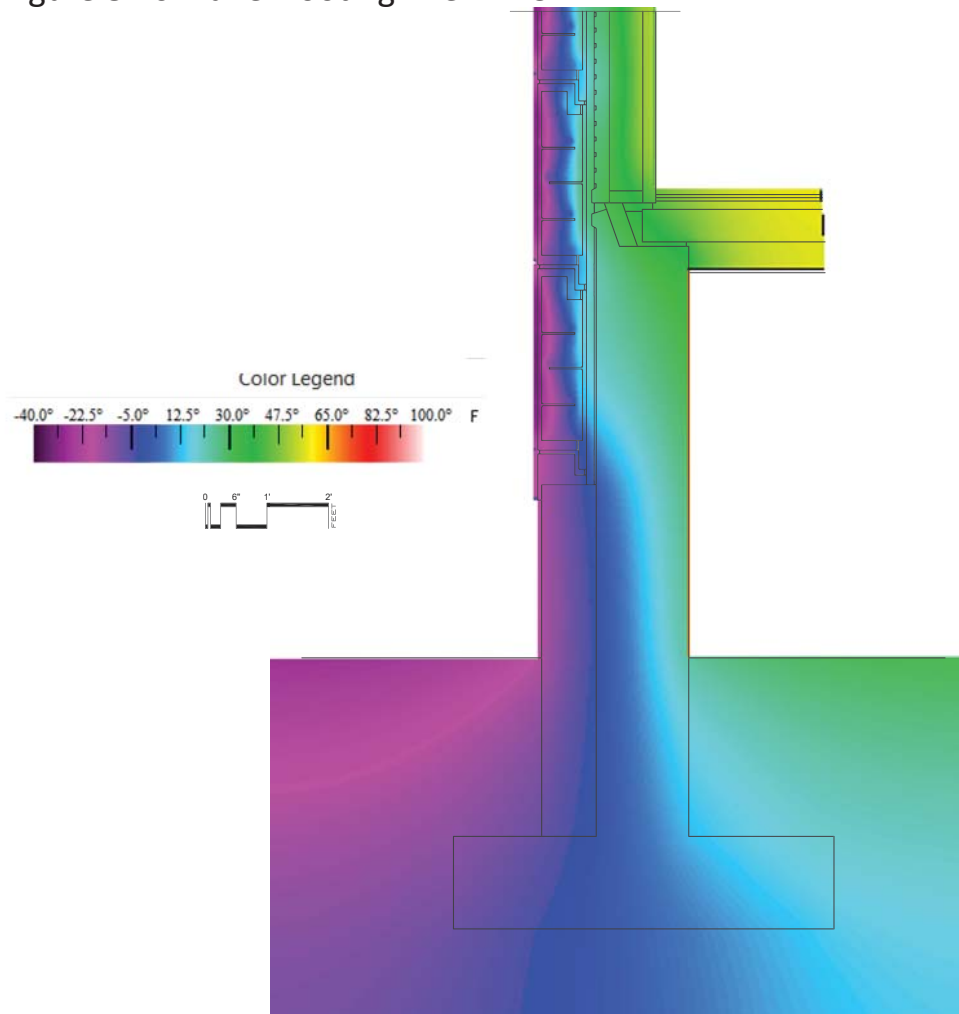


Figure 8.40: Panel Footing Therm7.3



existing footing of the building as shown in the footing wall detail in Figure 8.38. In the event that the footing needs to be strengthened then the footing can be strengthened first and then the prefabricated base panel can be placed on top of the footing and then secured against the wall. A couple feet above ground, the footing panel will terminate and the sub-grid system will secure to this panel thereby taking the majority of the vertical load of the new panels. The remainder of the load will be carried by the existing structure, through the existing walls down to the foundation. When the new fiber cement panels are attached to the walls, a base cap will be placed at the bottom completing the base connection of the panel to the prefabricated footing. This is shown in Figure 8.39.

Finally, I input the footing into Therm 7.3 to check its thermal conductivity at the base cap location as shown in Figure 8.40. The results of the Therm analysis show that the panel is still very effective at minimizing thermal bridging through the material. By taking the panel down below the floor, thermal bridging is minimized at the footing location because the concrete will conduct heat out of the space far faster than the insulated fiber cement panels.

Conclusion: Case Study and Panel Redesign

The Practicum research conducted at Ferraro Choi and Associates has been a very beneficial and productive experience. Prior to the start of the Practicum semester, the fiber cement panel design had only been worked through in a basic panel section, while all the detail connections had yet to be worked through. During this portion of my doctorate thesis, the details on a variety of joint conditions were designed. In addition to this, it was very beneficial to closely study and analyze a few extreme cold weather condition exterior insulation systems. This gave key take aways to modify fiber cement panel design with airtight seals, along with a proper vapor barrier running continuously along the entire façade.

Crary Lab and South Pole Station had both successes and failures to learn from which in turn influenced the panel design, with the design improvements of silicone sealant bead and vapor barrier considerations.

In addition, after having discussions with Joe Ferraro, the question of adaptability to poor construction conditions also needed to be considered. One important benefit of the aluminum sub-grid system that holds the fiber cement panels to the exterior of the façade is that the grid is able to absorb imperfections in the existing façade conditions. It will be able to completely absorb unusual bulges and dips in the façade making a straighter and cleaner finished system.

Now that every joint condition for the fiber cement panel design in Russia has been thoroughly thought through, the design can move from the analytical to the aesthetic. The aesthetic benefit of the panel design is inherent in the freedom and flexibility of fiber cement as the panel finish. They can take on many shapes and sizes and as such can lead to very interesting design aesthetics. In the next section, we will be seeing a finished redesign of the exterior façade at the site location in Volzhsky. The goal of this redesign is to showcase the potential design aesthetic potential of the fiber cement panels so that as these panels are employed throughout Russia, they can begin to take on a more unique appearance.

Chapter 9: Final Design

In order to properly demonstrate the versatility of the aesthetic capabilities of the fiber cement insulated panels, it is essential to do an exterior redesign of the existing building façade on the site location in Volzhsky. The building itself presents a complicated design problem because it is so extremely long in both directions. This causes the subtle details of the panel finishes to be lost on such a large scale façade and as such the entire building can look very monolithic because it is so massive. In order to properly address this design problem, a variety of panel shapes were conceived that would attach to the exterior façade with different angled designs that can be used to create drama on an otherwise massive and simple façade surface. The design concept was inspired by the Walgreens Store on Kapiolani Blvd, in Honolulu, Hawaii, which was designed by Architects Hawaii. Some photos of the Walgreens design are shown in Figures 9.1-9.3. The design incorporates metal angled panels in order to accomplish a very dynamic and dramatic façade exterior. This façade typology is perfect for the building in Volzhsky, because it will help create a façade that reveals texture and scale even when seen at a distance. In the final design in Volzhsky, there are more than 10 different panel shapes randomly placed throughout the façade in order to create a very dramatic effect. The overall objective was to create the look of an undulating exterior surface.

Changing the panel shape helped to address the massive monolithic quality of the building. The next major design challenge addressed was the lack of a formal entry. The building is made up of a series of four unit floor plans with each four unit segment having its own small lobby and entry area. These entry points are located inside the building courtyard. The building is shaped like a large L. The outside of the L parallels

Figure 9.1: Walgreens Kapiolani Design Precedent
<http://steelencounters.com/walgreens-honolulu-82015/4590519128>



Figure 9.2: Walgreens Kapiolani Design Precedent
<http://steelencounters.com/walgreens-honolulu-82015/4590519128>



Figure 9.3: Walgreens Kapiolani Design Precedent
<http://www.bizjournals.com/pacific/news/2014/07/15/walgreens-to-open-flagship-hawaii-store-inearly.html>



the street and the interior houses a large courtyard/promenade area between the 9-story typology that surrounds the perimeter of the micro district and the older 5-story typology that is on the interior of the micro district.

Because the building is so large, there are periodic pass-through points that occur in the building where the first floor unit is not built and instead a covered walkway through the building is in its place, allowing for people to get from the street side to the courtyard side of the building. This allows them to enter their perspective units once in the interior courtyard area. The new design incorporates a formal entry point as well as highlights the other entry points along the building façade through which people can enter the interior courtyard area. The entry was placed in the 90 degree angle created by the two sides of buildings L-shaped wings. In order to direct pedestrian traffic flow to this location, a very dramatic awning system was created that would shade the sidewalk below from and while at the same time create a dramatic focal point of the building that directs people through the building and into the interior of the space. The awning itself is an aluminum triangular shaped trellis. They comprised of overlapping triangular angles that create a dramatic shadow effect on the walkway below.

In Figures 9.4 and 9.5, you can see before and after renderings of the building design. The new panels are a dark charcoal grey which creates a strong contrast with the surrounding environment. In addition, this design will have better heat gain during the winter months making the panels more effective at retaining heat on the interior of the spaces. Figure 9.6 shows the lighting effect of the building at night with an awning system that lights up to provide light for the walkways below and creates drama with the angled panels at night as well as during the day. Figure 9.7 is an original basic finish design, while Figure 9.8 shows the angled panel design that was incorporated in the design in Volzhsky. In addition, Figures 9.9 and 9.10 show the walkway area with the trellis system overhead.

Figure 9.4: Site Location Before Renovation
Google Earth Image

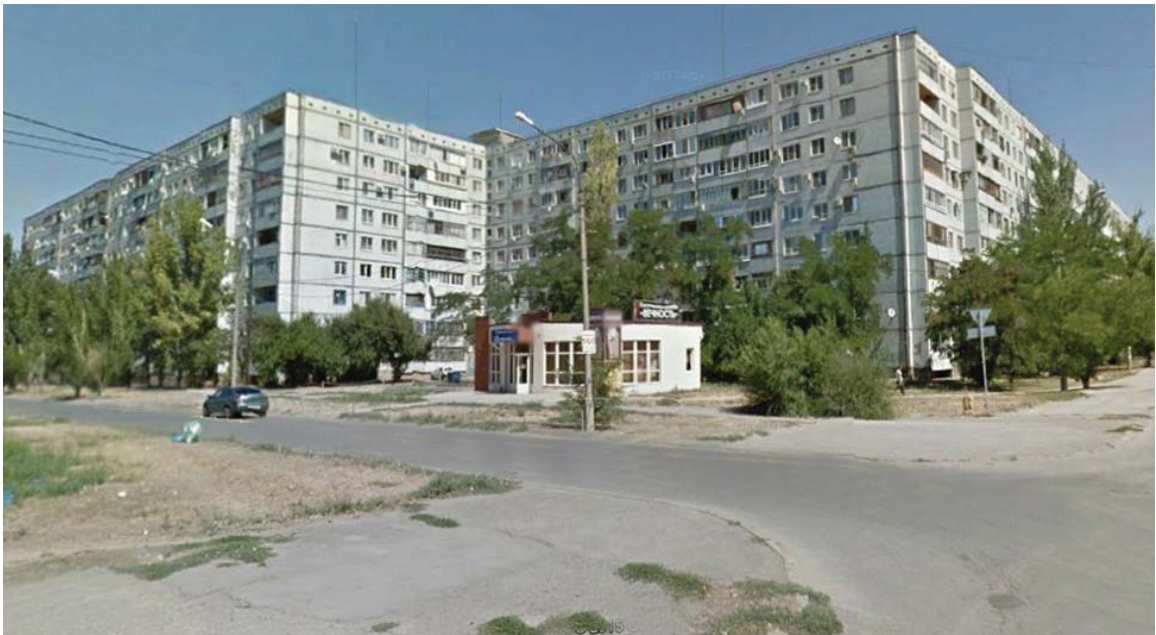


Figure 9.5: Site Location After Renovation



Figure 9.6: Exterior Building Rendering



Figure 9.7: New Fiber Cement Panel Figure 9.8: Angled Panel Close Up



Figure 9.9: Exterior Walkway Rendering



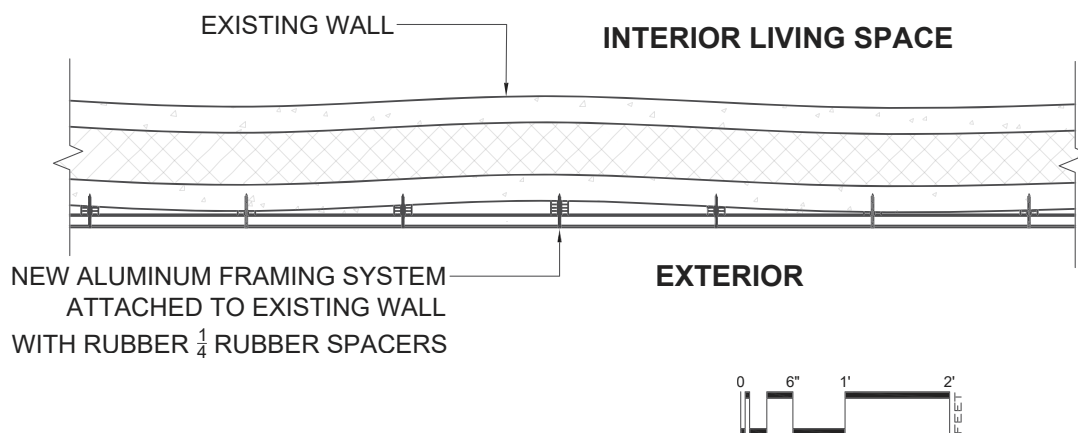
Figure 9.10: Exterior Walkway Evening Rendering



Building Retrofit Construction Process

The window is designed to be prefabricated and delivered to the construction site to be installed. During the renovation of the building, the existing windows will be removed and then the new aluminum framing system will be installed on the entire façade. Before the framing system can be installed the base of the framing system must be attached to the existing footing condition. From there the entire frame can be attached to the façade of the building. Because the original building like all the other buildings of this nature throughout the country were built so poorly, it is a fair assumption that the building is not perfectly square. All of the existing walls and corners will most likely have imperfections from the original construction process. To compensate for this complication, rubber spacers should be used to fill the gaps between the new aluminum framing system and the existing wall as is demonstrated in Figure 9.11.

Figure 9.11: Wall Framing Spacer Drawing



After the framing system has been installed and squared the new triple pane window with a fiber cement frame will be installed. Because these windows are so large and are triple pane they are incredibly heavy, this weight is then increased by the weight of the fiber cement frame. The standard window is over 300 lbs and the windows that are located on the balcony are even heavier. Because of their weight they require a crane or heavy duty pulley system to install. This was taken into account in the cost savings of the design, as the design by VTT Technical already accounted for a total expense to install the new triple pane windows. Since the window weight is primarily in the weight of the window itself and not the new fiber cement frame. The cost will be roughly the same to install the windows as in the VTT Technical retrofit study.

After the windows are installed throughout the entire building, the new panels can be installed from the top down. In the details of the jambs and head of the window, a small angled fiber cement cap will be installed after the wall panels have been installed. These angled pieces are a purely aesthetic feature designed to make the window frame look symmetrical on all sides. Finally, once all the panels have been installed, the base cap is installed at the connection between the bottom panel and the micro rebar base. Because there may be some varying field conditions the entire building should be measured and field verified prior to start of construction.

Construction Documents

Throughout this entire paper, there has been a variety of detail drawings of the design as it has progressed. The remaining figures in this chapter show a complete compilation of all the drawings that were created in order to further demonstrate the panel design and its capabilities. The panels are extremely versatile in their capabilities and they are adaptable to a variety of building typologies. These panels will not only improve the thermal efficiency of these buildings exterior envelope skin, but will do so in a manner that is more cost effective and aesthetically appealing than any other system currently on the market today.

Figure 9.12: 9-Story Typical Floor Plan: Volzhsky
Soviet Union, "Arkhitectura SSSR: 1963," no. 1, Page 14

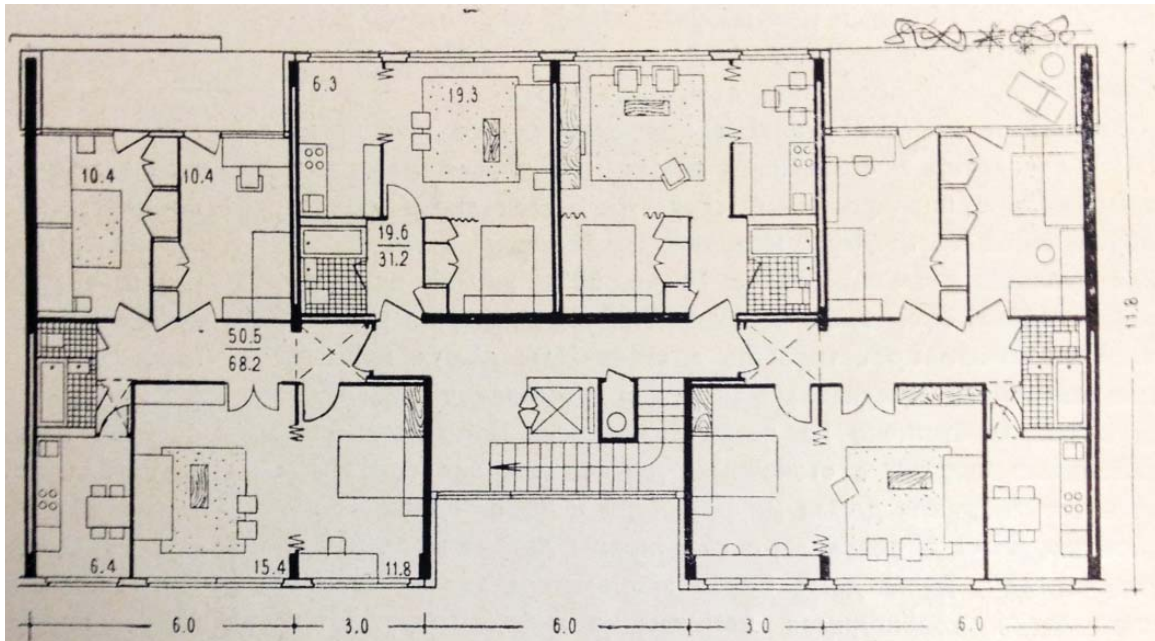


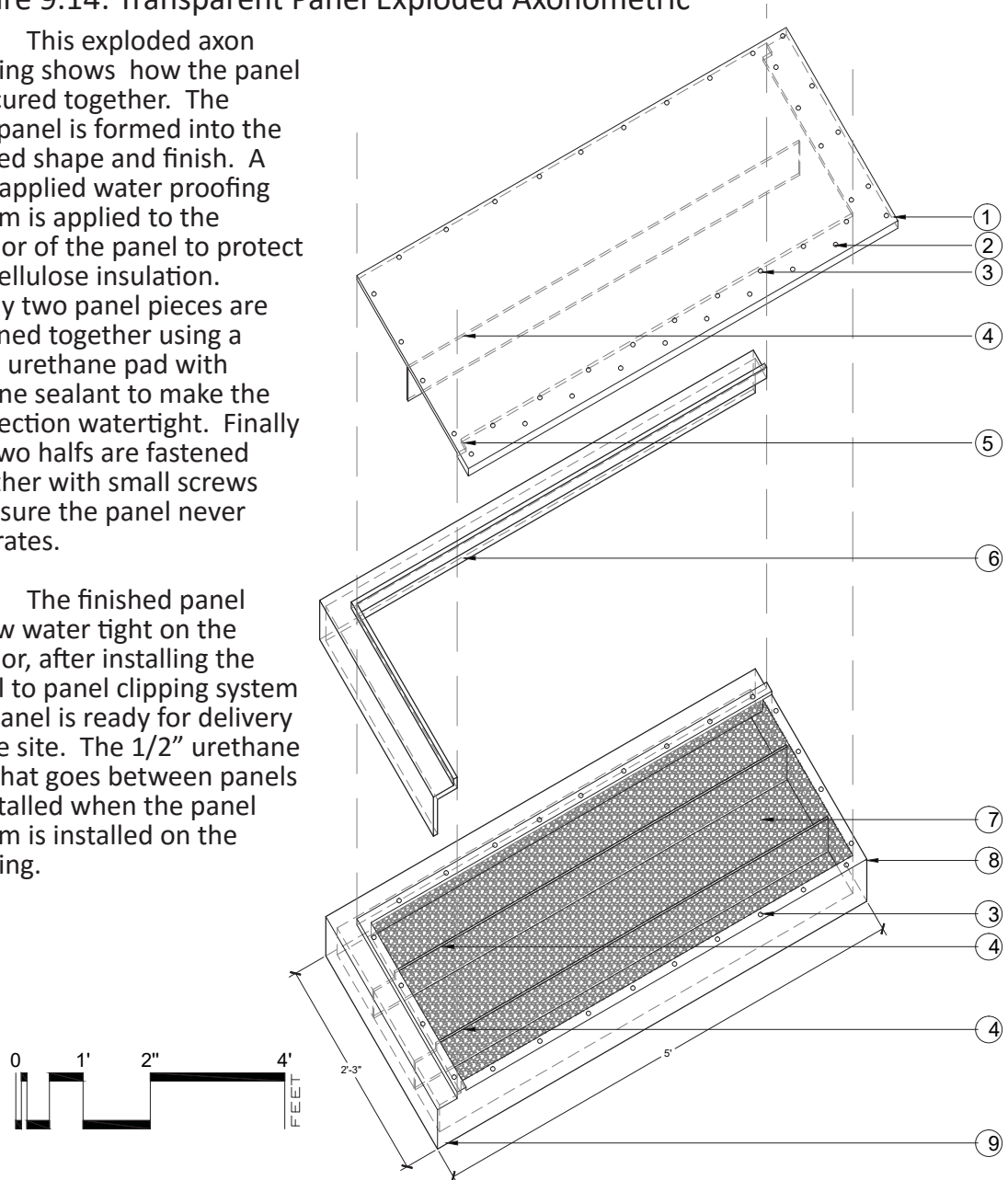
Figure 9.13: New Fiber Cement Panel



Figure 9.14: Transparent Panel Exploded Axonometric

This exploded axon drawing shows how the panel is secured together. The new panel is formed into the desired shape and finish. A fluid applied water proofing system is applied to the interior of the panel to protect the cellulose insulation. Finally two panel pieces are fastened together using a small urethane pad with silicone sealant to make the connection watertight. Finally the two halves are fastened together with small screws to ensure the panel never separates.

The finished panel is now water tight on the interior, after installing the panel to panel clipping system the panel is ready for delivery to the site. The 1/2" urethane pad that goes between panels is installed when the panel system is installed on the building.



1. BACKSIDE OF PREFABRICATED FIBER CEMENT PANEL
2. BOLT LOCATIONS TO FASTEN PANEL TO ALUMINUM FRAME ON THE EXTERIOR OF THE BUILDING
3. BOLT LOCATIONS THAT FASTEN THE TWO PIECES OF THE PANEL TOGETHER WITH URETHANE THERMAL BREAK AT THE CONNECTION INTERIOR HIGH DENSITY URETHANE FIN FOR INTERIOR STABILITY
4. FIBER CEMENT FIN TO STABILIZE THE INTERIOR OF THE PANEL
5. 1/2" JOINT STEP DOWN
6. URETHANE CLOSED CELL FOAM CONNECTION PAD BETWEEN PANELS FOR WATER PROOFING, MINIMIZING THERMAL BRIDGES AT CONNECTIONS AND IMPROVED INSULATION AT THE JOINT CONDITION
7. CELLULOSE INSULATION WET APPLIED
8. EXTERIOR PREFABRICATED FIBER CEMENT PANEL WITH INTERIOR FLUID APPLIED WATER PROOFING COATING TO MAKE WATER TIGHT.
9. FACE OF EXTERIOR PREFABRICATED FIBER CEMENT PANEL (MANY FORMS, FINISH OR COLORS)

Figure 9.15: Transparent Panel Axon Detail

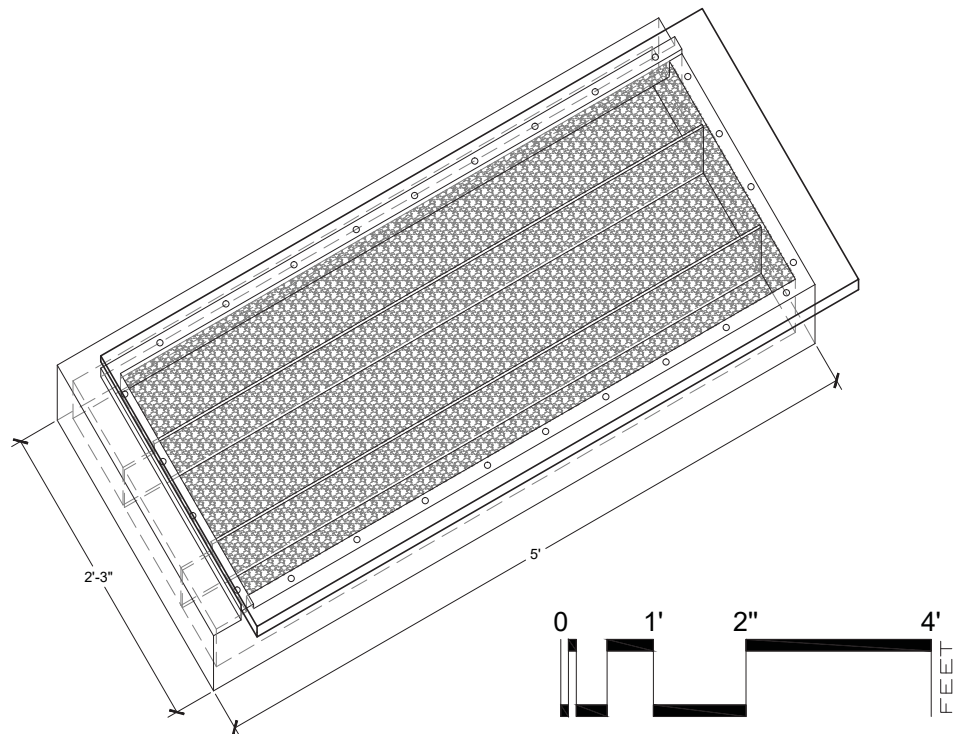


Figure 9.16: New Fiber Cement Panel

PANEL FACTS:

Fiber Cement (Density:350 kg/m3):

Cross Section Area = $22.14 \text{ in}^2 + 20.51 \text{ in}^2 = 42.65 \text{ in}^2 = 0.296 \text{ ft}^2$ Total Volume = $0.296 \text{ ft}^3 \times 5 \text{ ft} = 1.48 \text{ ft}^3 = 0.0419 \text{ m}^3$

Fiber Cement Total Mass= 14.67 kg

Insulation (Density:56kg/m3):

Cross Section Area = $103.42 \text{ in}^2 = 0.718 \text{ ft}^2$ Total Volume = $0.718 \text{ ft}^2 \times 5 \text{ ft} = 3.905 \text{ ft}^3 = 0.112 \text{ m}^3$

Mass= 6.72 kg

Urethane Thermal Barrier (Density:30kg/m3):

Cross Section Area = $.31 \text{ in}^2 + .31 \text{ in}^2 = .62 \text{ in}^2 = 0.004 \text{ ft}^2$ Total Volume = $0.004 \text{ ft}^2 \times 5 \text{ ft} = 0.02 \text{ ft}^3 = 0.00057 \text{ m}^3$

Mass= 0.0171 kg

Urethane Joint Between Top and Bottom Panels (Density:30 kg/m3):

Cross Section Area = $4.21 \text{ in}^2 = 0.029 \text{ ft}^2$ Total Volume = $0.029 \text{ ft}^2 \times 5 \text{ ft} = 0.145 \text{ m}^3 = 0.0041 \text{ m}^3$

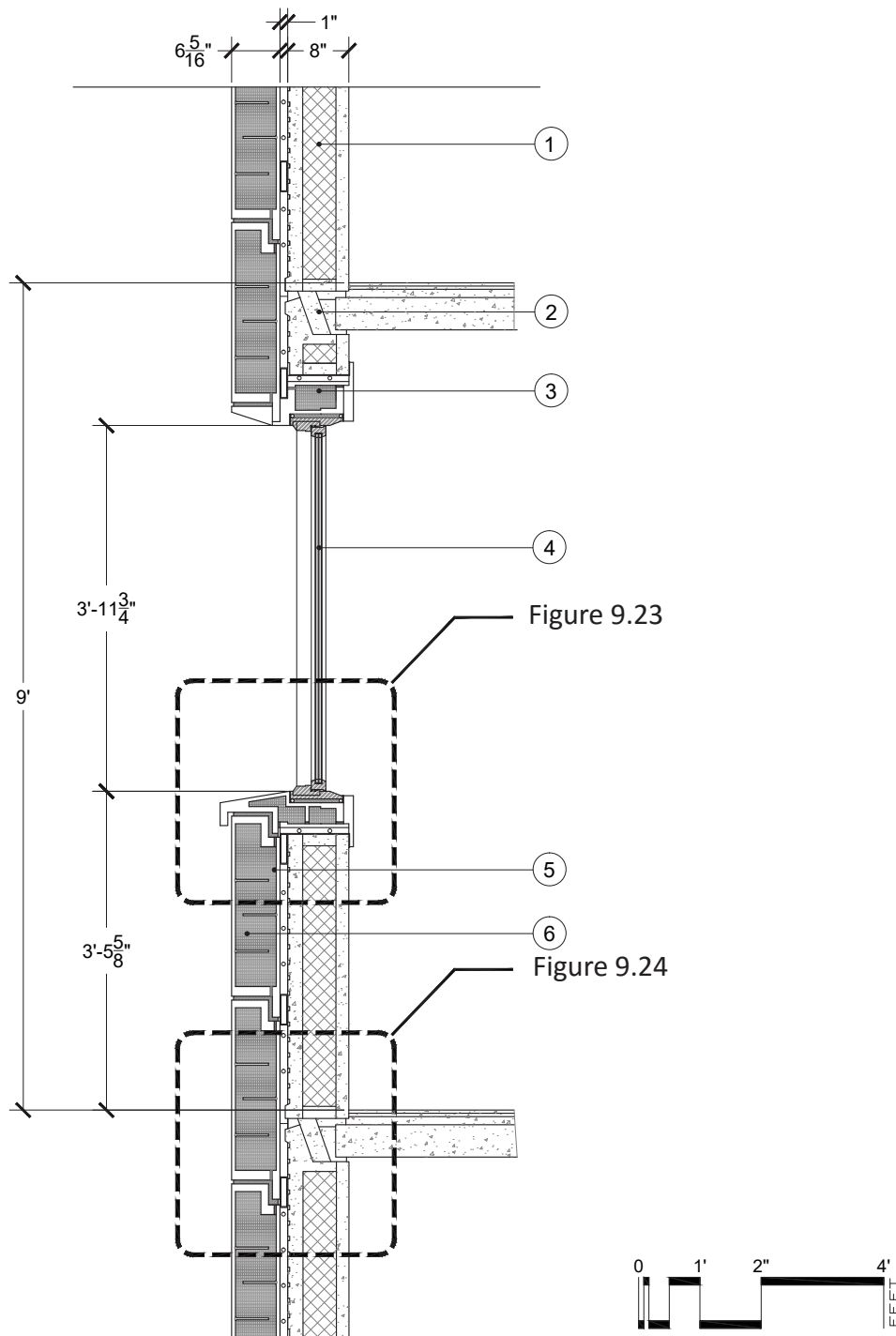
Mass= 0.123 kg

Typical Panel Weight= 21.53 kg = 47.47 lbs

Typical Wall Original Weight = 682 - 800 kg or 1499 -1763 lbs

New Panel Roughly Increasing Overall Wall Weight by Around 10%

Figure 9.17: Fiber Cement Panel Wall Section



1. EXISTING RUSSIAN PREFABRICATED CONCRETE SANDWICH PANEL
2. EXISTING RUSSIAN PREFABRICATED CONCRETE PANEL FLOOR AND JOINT CONDITION.
3. NEW PREFABRICATED FIBER CEMENT WINDOW FRAME
4. NEW TRIPLE PANE, ARGON FILLED, LOW E GLASS OPERABLE WINDOW.
5. NEW PREFABRICATED INSULATED FIBER CEMENT PANELS
6. CELLULOSE INSULATION INTERIOR

Figure 9.18: Balcony Open Prior to Retrofit

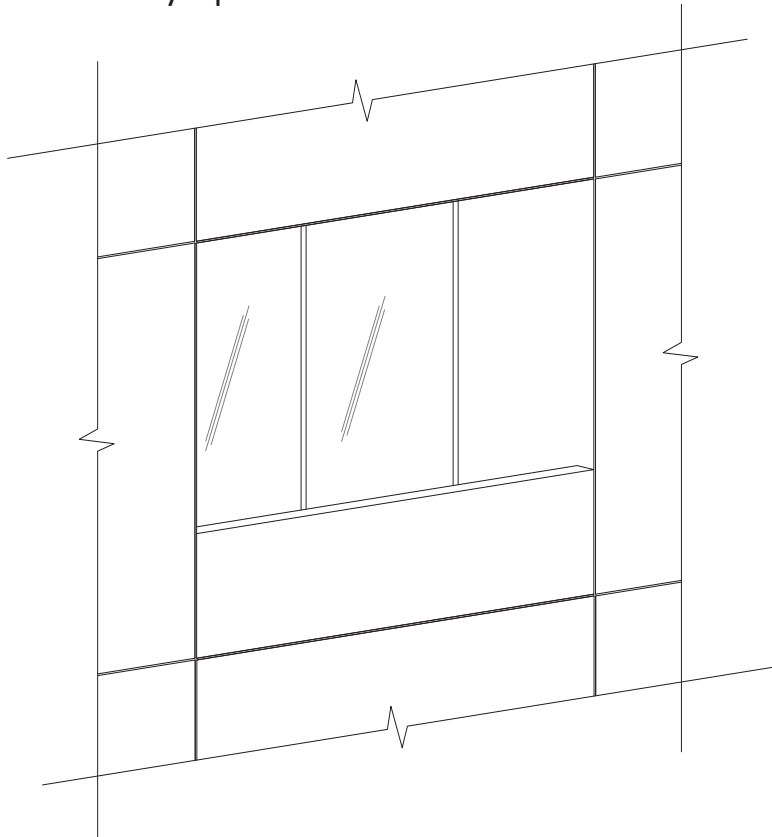


Figure 9.19: Balcony Enclosed After Retrofit

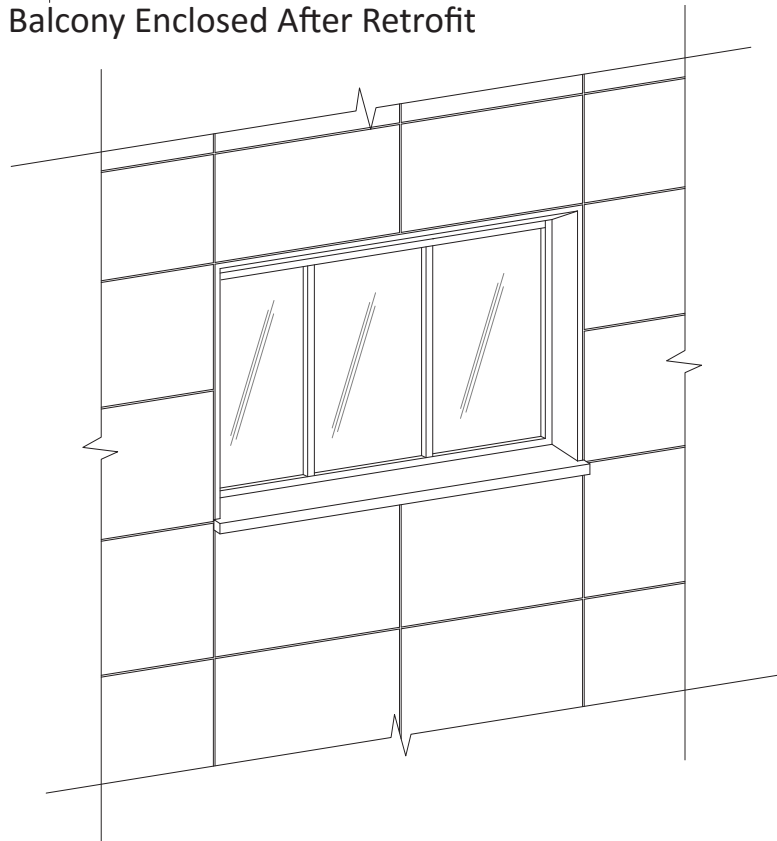


Figure 9.20: Fiber Cement System Construction Axon

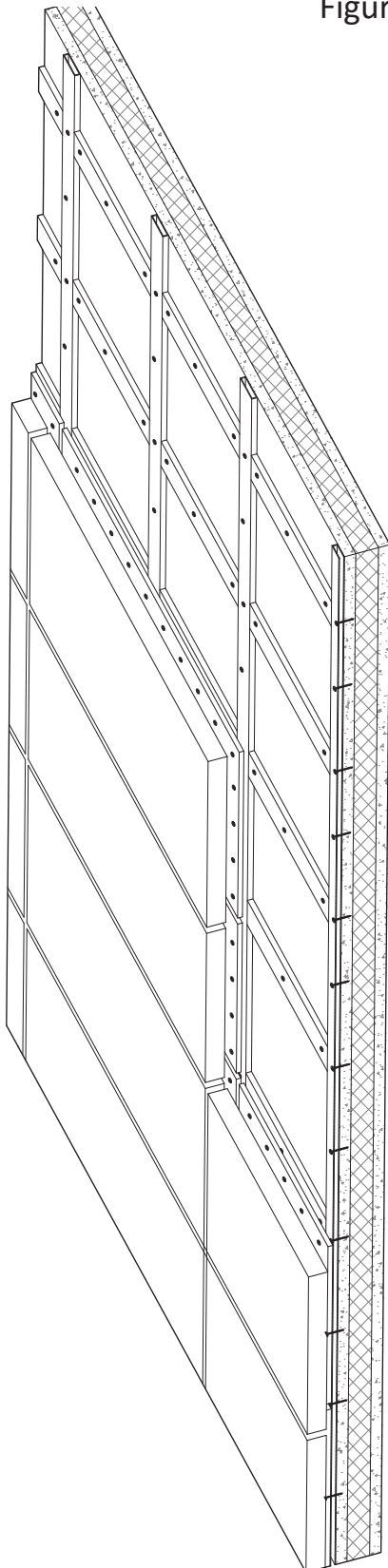
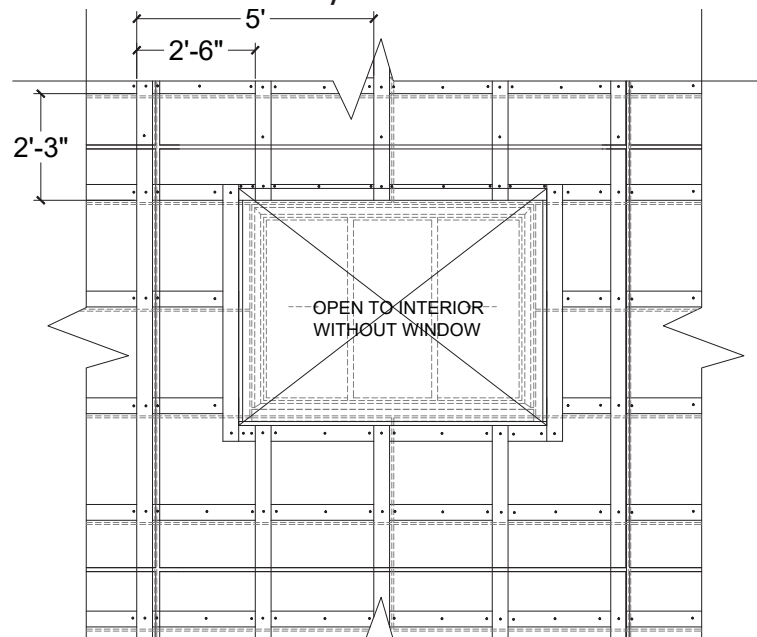


Figure 9.21: Fiber Cement System Sub Grid



NOTE:
GRID SPACING TO BE LAID OUT IN A 2'-6"X2'-3" PATTERN. FOR SPACES AROUND WINDOW OPENINGS GRID PATTERN IS TO BE ALTERED TO FIT ACCORDINGLY.

GRID IS TO BE SCREWED TO FACADE WITH CONCRETE SCREWS
MAXIMUM SPACING @ 18" O.C.

NEW FIBER CEMENT PRE FABRICATED PANEL IS SECURED TO SUB-GRID. GRID PROVIDES LEVEL PLAIN TO SECURE PANELS TO AS WELL AS AN AIR GAP BETWEEN THE PANEL AND BUILDING FACADE FOR INCREASED INSULATION VALUE

Figure 9.22: Fiber Cement System Elevation

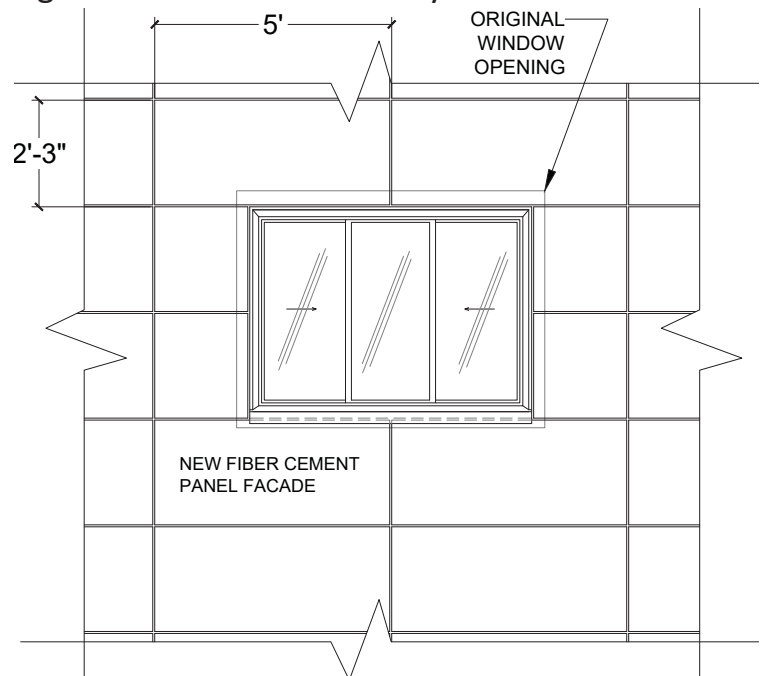


Figure 9.23: Window Section Detail

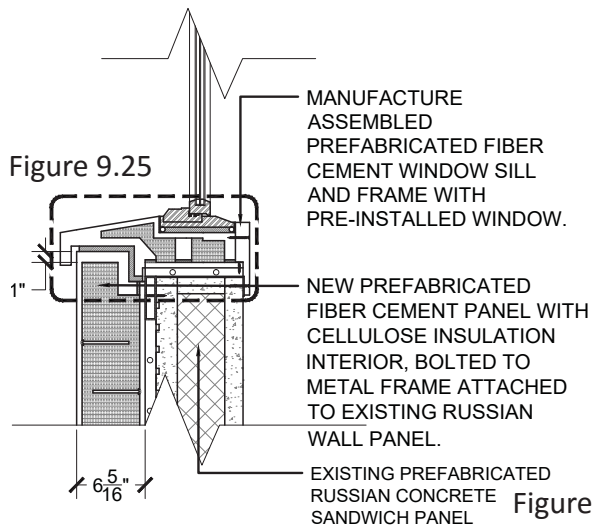


Figure 9.24: Wall Panel Section Detail

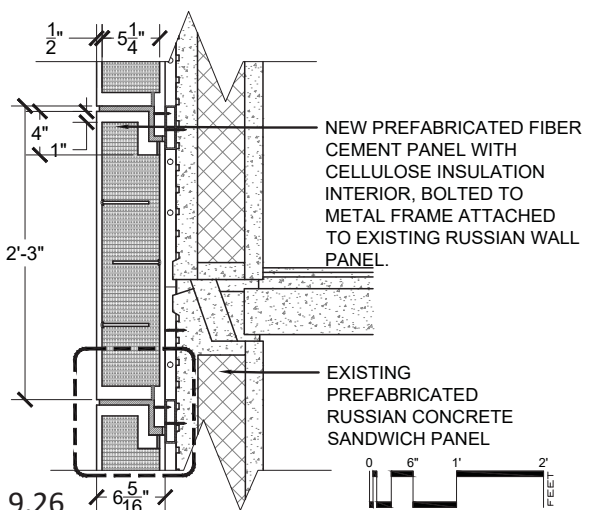


Figure 9.25: Panel to Panel Call-Out Detail

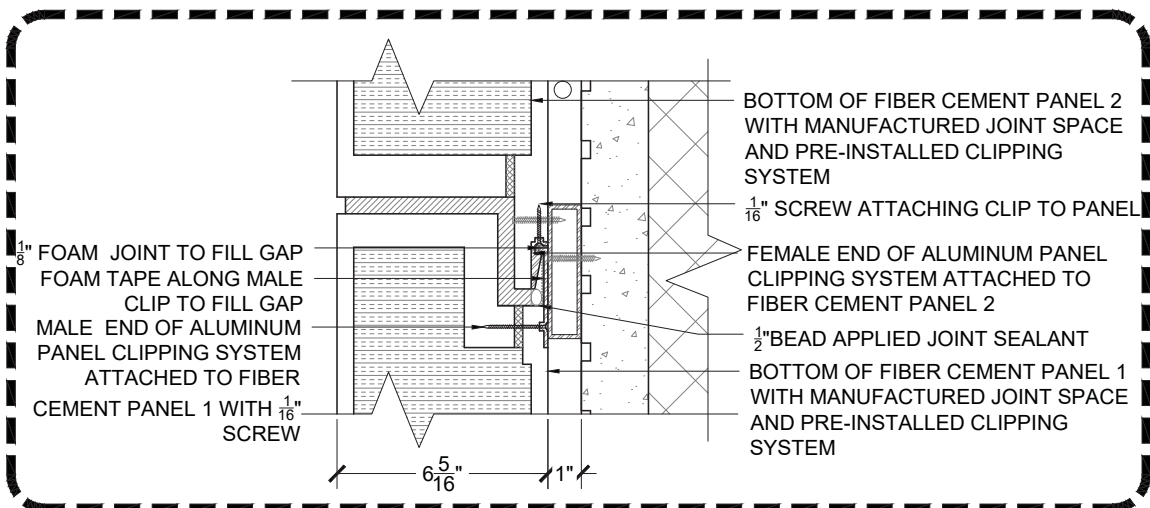


Figure 9.26: Window Sill Call-Out Detail

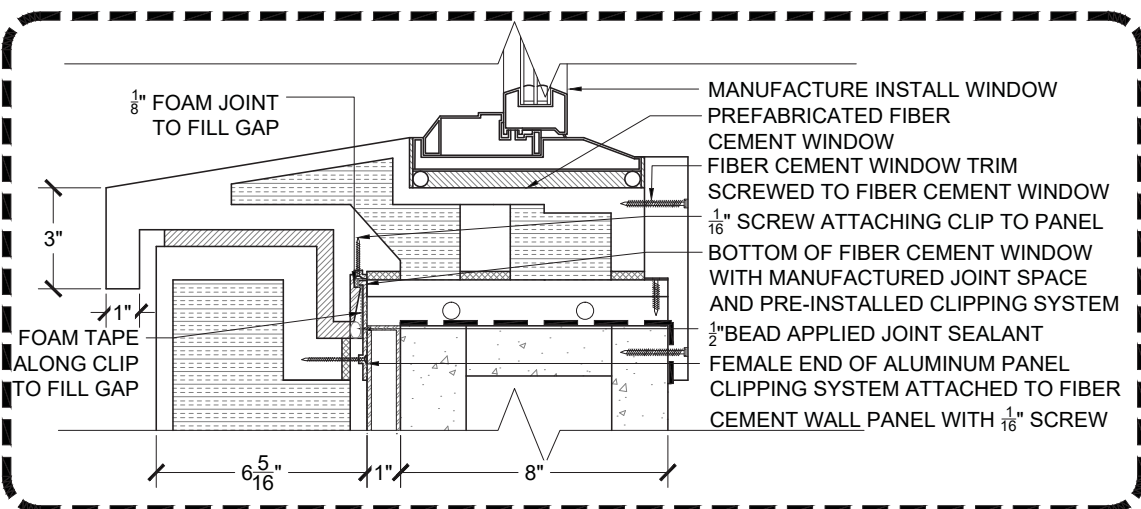


Figure 9.27: Panel Design Plan

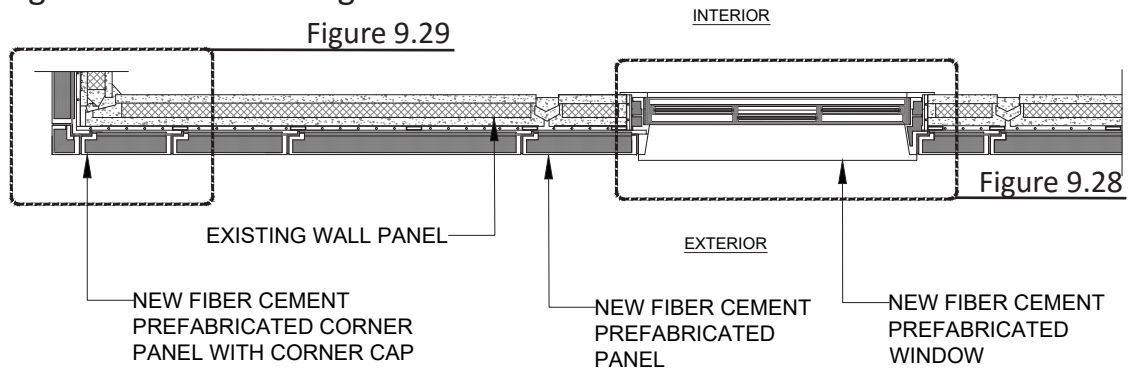
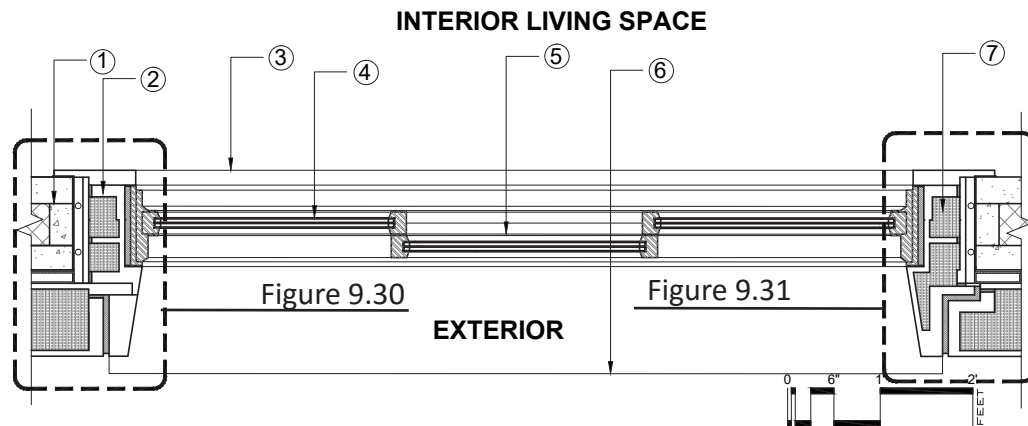


Figure 9.28: Window Plan Detail



1. EXISTING RUSSIAN WALL PANEL
2. LEFT FIBER CEMENT PREFABRICATED JAM WITH CELLULOSE INSULATION INTERIOR.
3. NEW TRIPLE PANE WINDOW ARGON GAS FILLED WITH LOW-E FILM ON BOTH INTERIOR AND EXTERIOR.
4. SLIDING WINDOW
5. FIXED WINDOW
6. WINDOW SILL
7. RIGHT FIBER CEMENT PREFABRICATED JAM WITH CELLULOSE INSULATION INTERIOR.

Figure 9.29: Corner Plan Detail

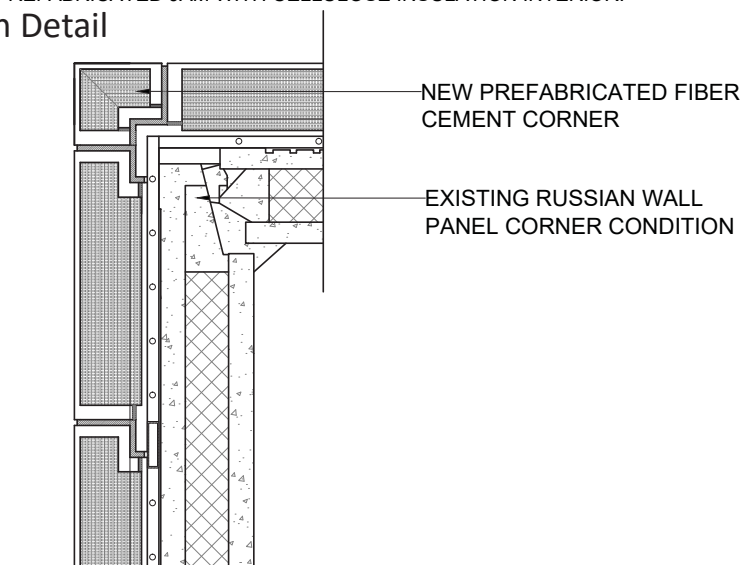


Figure 9.30: Left Window Jamb Plan Detail

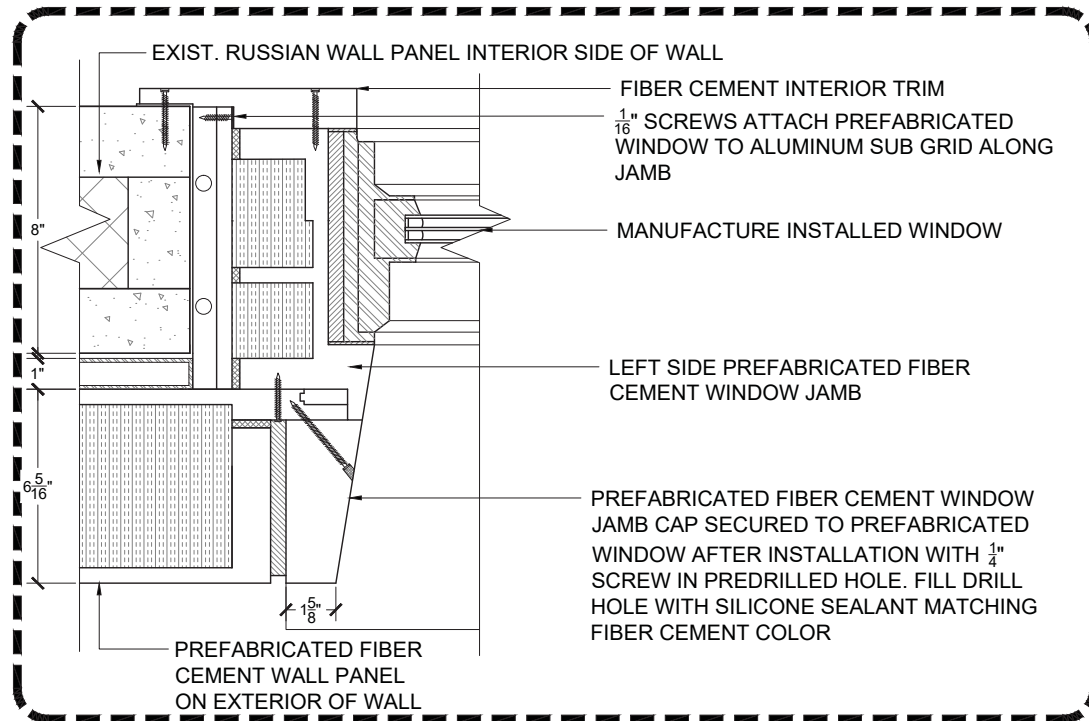


Figure 9.31: Right Window Jamb Plan Detail

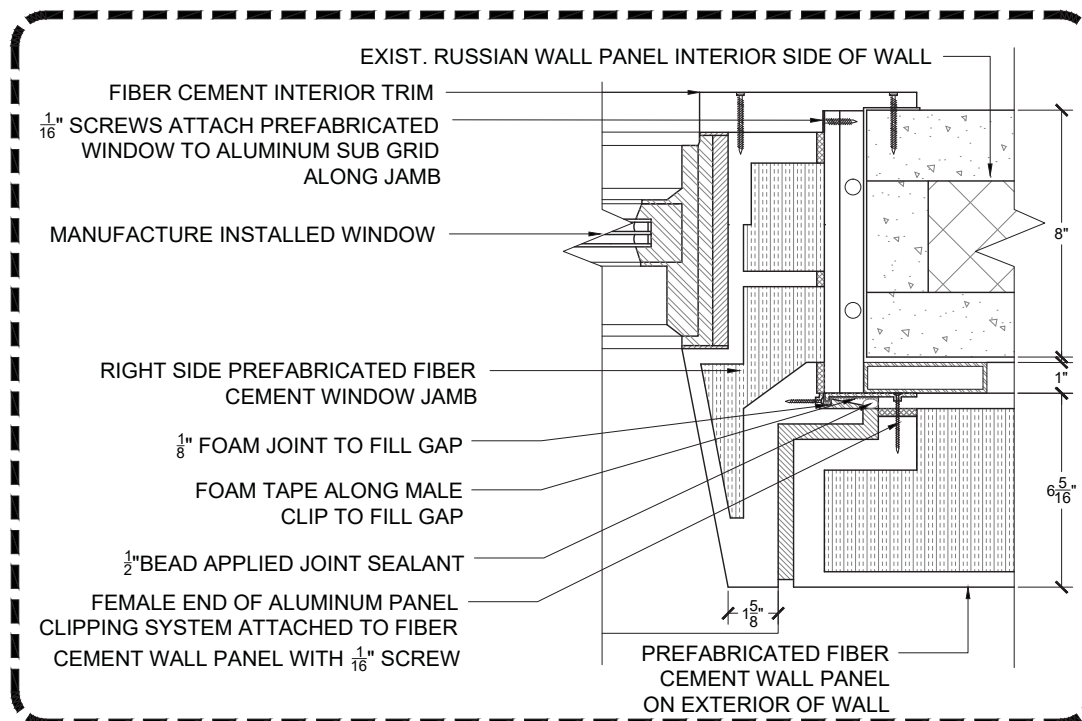
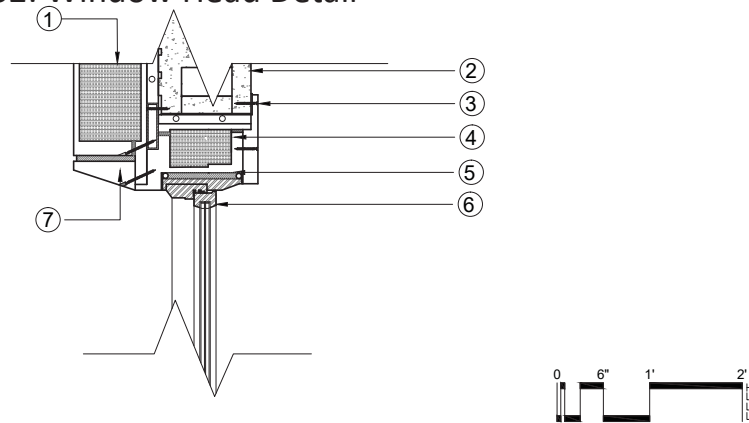


Figure 9.32: Window Head Detail



1. NEW PREFABRICATED FIBER CEMENT PANEL WITH CELLULOSE INSULATION
2. EXISTING RUSSIAN WALL PANEL
3. INTERIOR PREFABRICATED FIBER CEMENT WINDOW TRIM FASTENED TO NEW PREFABRICATED FIBER CEMENT INSULATED WINDOW PANEL FRAME WITH $\frac{1}{4}$ " SCREWS
4. MANUFACTURE ASSEMBLED PREFABRICATED FIBER CEMENT WINDOW SILL AND FRAME WITH PRE-INSTALLED WINDOW.
5. SILICONE SPACERS ON BED OF SILICONE
6. MANUFACTURE INSTALLED SLIDING INTERIOR WINDOW FRAME
7. NEW WINDOW HEAD END CAP SECURED TO PREFABRICATED WINDOW AFTER INSTALLATION WITH $\frac{1}{4}$ " SCREW IN PREDRILLED HOLE. FILL DRILL HOLE WITH SILICONE SEALANT MATCHING FIBER CEMENT COLOR

Figure 9.33: New Prefabricated Window



Figure 9.34: Panel Footing Wall Section

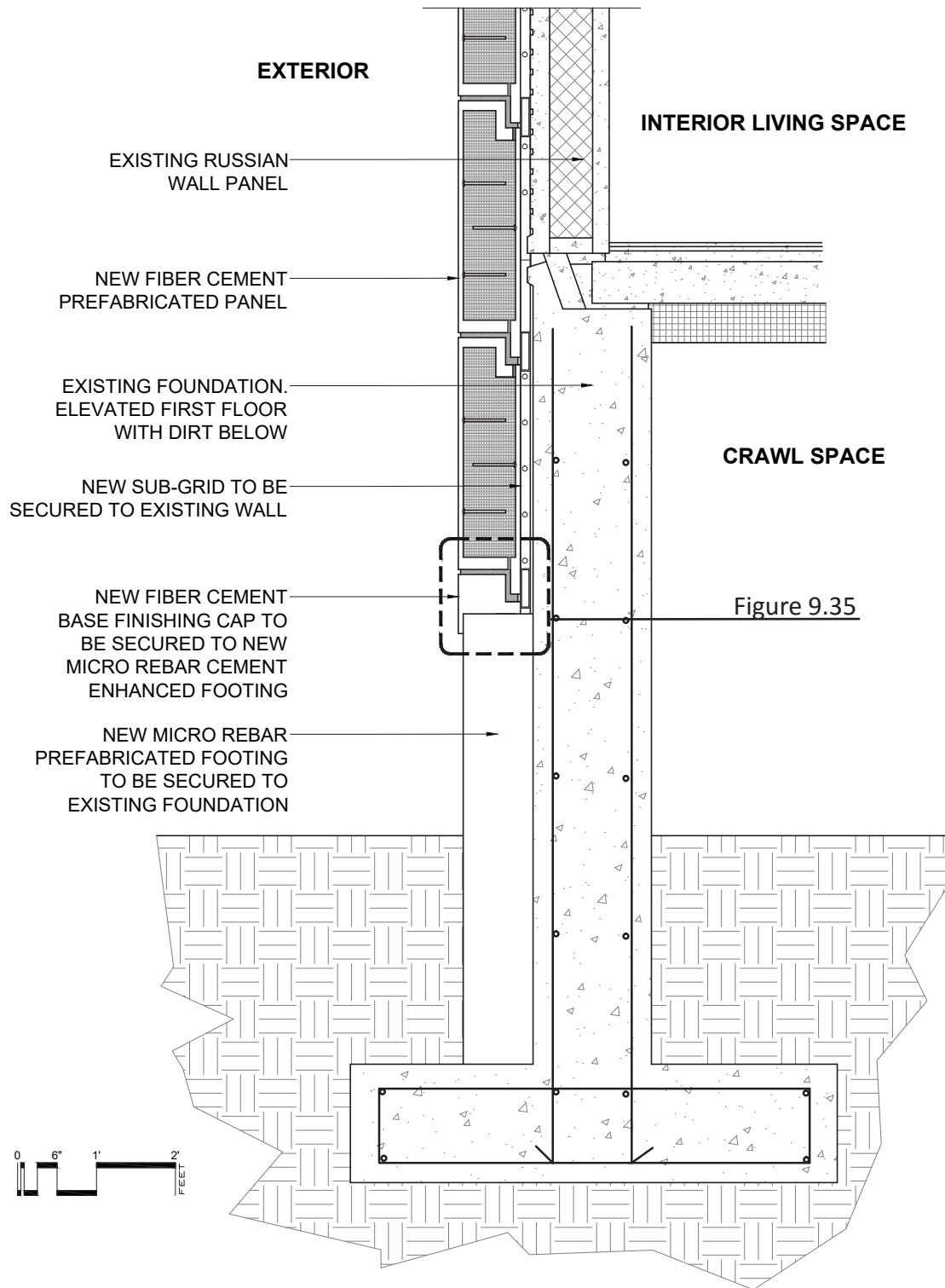


Figure 9.35: Panel Base Cap Detail

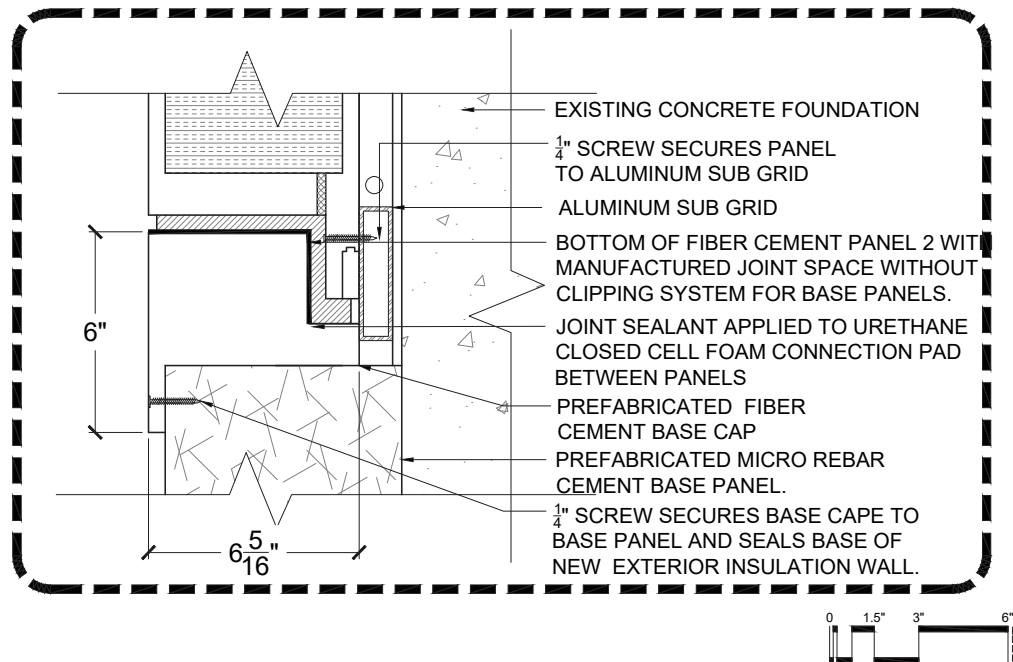


Figure 9.36: Roof Parapet Wall Section

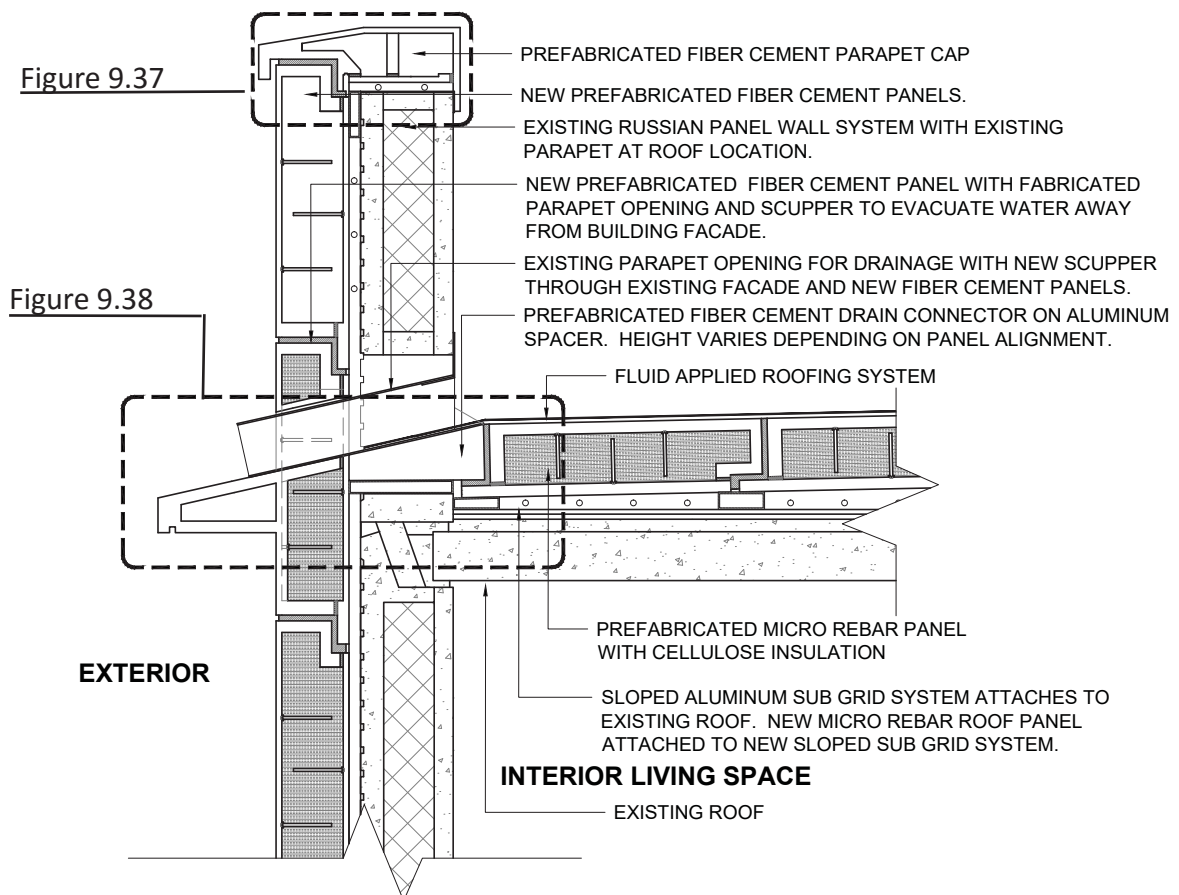


Figure 9.37: Parapet Cap Call-Out Detail

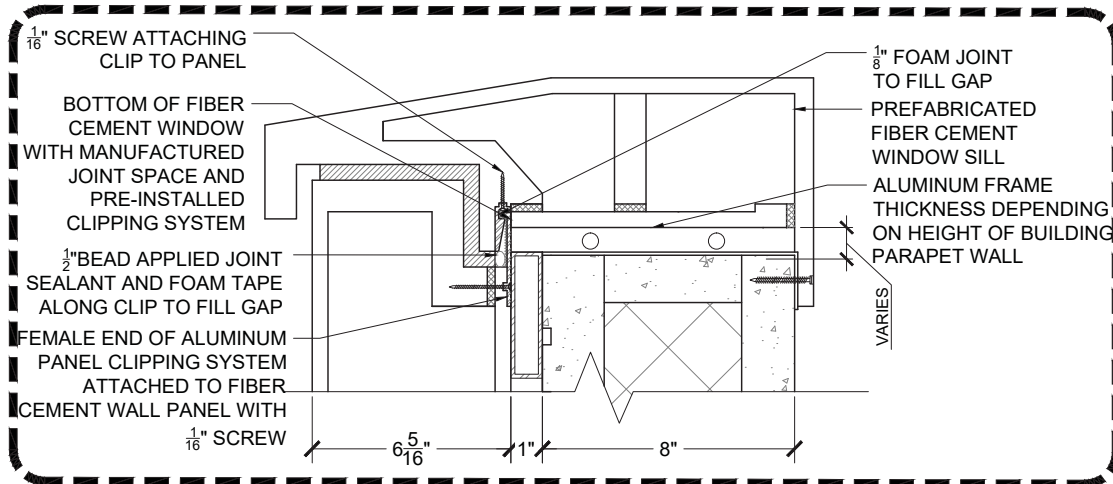


Figure 9.38: Parapet Scupper Call-Out Detail

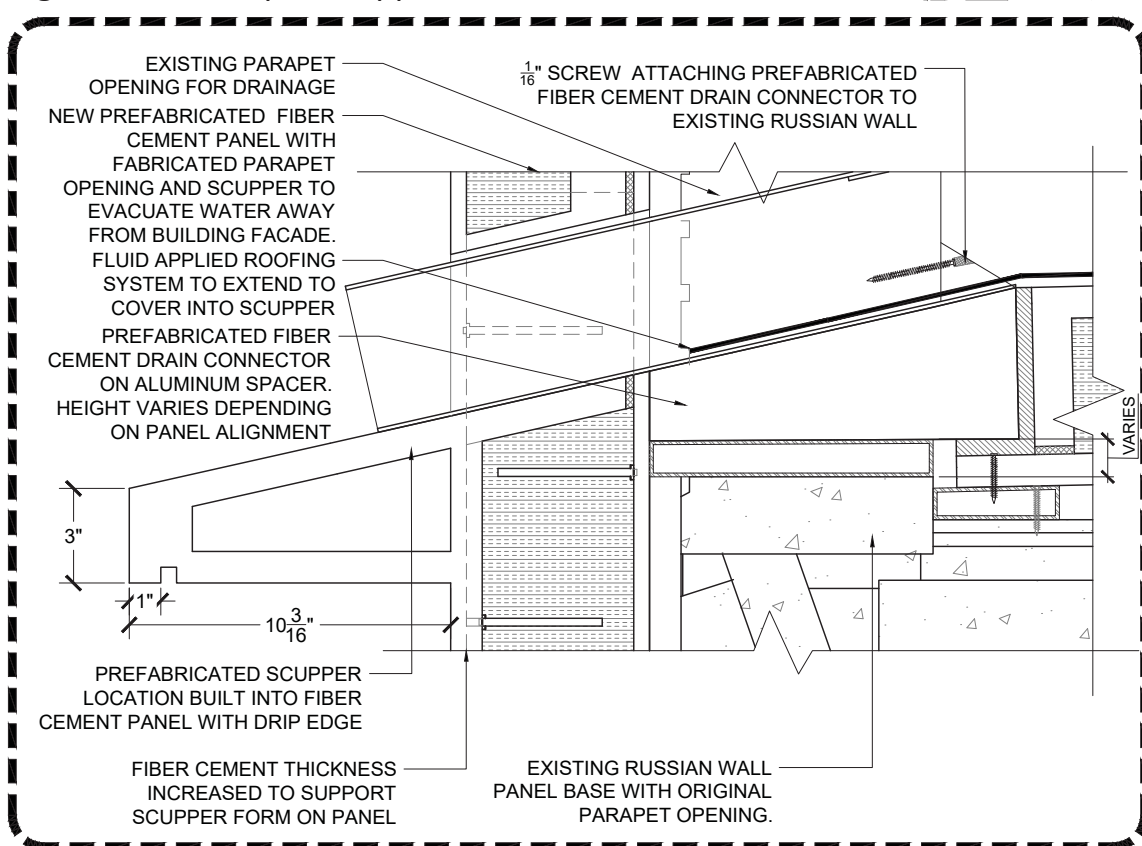
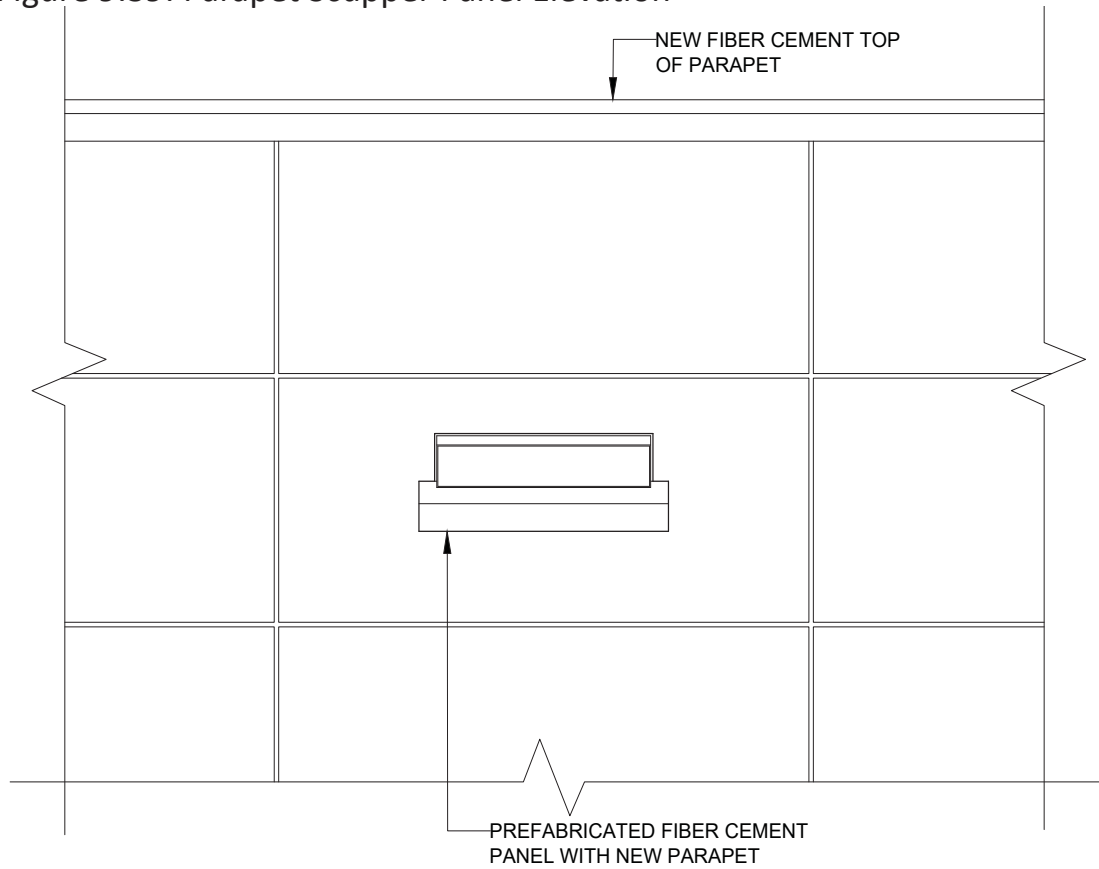


Figure 9.39: Parapet Scupper Panel Elevation



Chapter 10: Conclusion

Russia has unique and advanced problems present in its residential sector. Providing adequate residential units has been a goal of the Russian government for over 80 years. While they have managed to provide housing to millions of their citizens, they have fallen short in the overall quality of these housing units. This was initially caused by their creation of a housing typology that was motivated by the need to maximize construction speed and minimize price, rather than being motivated by quality and thermal efficiency. The condition of these housing units has significantly deteriorated due to lack of maintenance. The design addresses the poor thermal efficiency and also significantly improves the aesthetics of these buildings. The information gathered in this doctorate project was done initially as pure research: examining what had been done and where the problems were, both economically and in the design limitations. The second portion of this doctorate project was design research. Examining different building materials, performing case studies and determining the best alternatives was all part of the design research and shaped the foundation of the new design alternatives that have been developed.

There has been substantial progress made in the case studies and retrofit test options that were conducted in Moscow in the past 20 years. VTT Technical gave Russia an impressive potential solution to their retrofit problem across the country. However, as the test was concerned mainly with applying a simple, relatively inexpensive, easy to implement retrofit solution, it lacked innovation which in turn limited the overall potential for it to be implemented across the county.

After a very thorough material analysis, it was clear that a far superior option was fiber cement with cellulose insulation. The new fiber cement panel system presented

a very unique challenge because the cellulose insulation cannot support itself and therefore needed to be contained in some form of wall cavity, while at the same time had to be completely protected from any form of moisture. Addressing these design conditions lead to a visionary new building wall assembly system that is currently not in existence today. The design phase of this project uses simulation to estimate the insulating capability of various proposed wall assemblies with the goal of improving upon the previous iterations.

This project represents a step forward in building envelope design and retrofits, not only by its analysis of current building insulation and finish materials, but also in the synthesized approach to combine the best of these materials in a way that has never been done before. The new fiber cement panel with cellulose insulation that was created has the potential to revolutionize not only the building retrofits needed in Russia, but many other future building retrofits around the world.

It is a sustainable combination of materials that has the ability to contribute to LEED credits in building construction, and due to its ease of retrofit through the prefabrication process, it can be an affordable and superior alternative to any other construction systems, not only in Russia, but anywhere in the world as the same insulated fiber cement panels can be used to provide thermal efficiencies in both hot and cold climates. The system uses less embodied energy than any other insulated cladding system or insulated exterior finish system on the market, by combining the most sustainable, lowest cost materials available. In addition, with the material having a lifespan of 50 years or more with minimal to no maintenance, the buildings' overall lifetime maintenance costs will be substantially lower than with any other available option. There will always be a place for an aesthetically attractive, highly efficient, low cost exterior retrofit system. As the population of the world continues to grow, the need to do retrofits over more costly building replacements will become an increasingly

necessary option.

Throughout this research project, the fiber cement panel design has been continually refined. In the early stages it was refined using Therm 7.3 to determine thermal bridging in the panel section and joint locations. During the practicum semester, the case studies on Antarctic designs by Ferraro Choi, helped influence the joint connections and assemblies and gave much needed background knowledge which helped to refine the joint connections for the fiber cement panel design. This background knowledge gave assurances that as a variety of joint conditions were designed, that they were designed in a manner that would insure that the panel connections would be successful in avoiding thermal bridging through the insulation on the exterior façade of the building.

Once these connection details were worked through, it was possible to design a possible retrofit option on the site location in Volzhsky. These panels have been thoroughly thought through, in a manner that makes them ready to be taken into the manufacturing stage with initial mockups and physical testing so that in the event that Russia determines that they would like to use the panels for retrofits throughout the country, they can be implemented in a relatively short time period. These panels represent a massive step forward in prefabricated exterior insulation systems by creating a product that not only is effective at improving the insulation of the exterior façade of a building, but is also able to do so in a manner that is more sustainable and less expensive than any other system on the market today. When adding the fact that the panels are capable of taking on many shapes, textures and finishes, the versatility of these panels creates a dynamic design possibility in the retrofitting world that allows architects to redesign and improve the thermal insulation of these building in Russia as well as similar buildings throughout the world in an aesthetically appealing and cost effective way. The residents as well as the designers of these buildings will be able to control not only the

application and implementation of this building façade improvement, they will also have the ability to discuss and decide on different finishes rather than being limited by a very simple form which was inherent in the VTT Technical retrofit option.

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